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Bulletin 660

CONTRIBUTIONS TO ECONOMIC GEOLOGY

(SHORT PAPERS AND PRELIMINARY REPORTS)

1917

PART I.—METALS AND NONMETALS EXCEPT FUELS

F. L. RANSOME, E. F. BURCHARD, AND H. S. GALE
GEOLOGISTS IN CHARGE

WASHINGTON
GOVERNMENT PRINTING OFFICE
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NOTE.—The Survey's annual volumes entitled "Contributions to economic geology" are issued in parts, and the last part will include a volume title-page, table of contents, and index for the use of those who may wish to bind the separate parts. A small edition of the bound volume will also be issued, but copies can not be supplied to those who have received all the parts.

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PART I. METALS AND NONMETALS EXCEPT FUELS.

F. L. RANSOME, E. F. BURCHARD, and H. S. GALE, *Geologists in charge.*

INTRODUCTION.

The Survey's "Contributions to economic geology" have been published annually since 1902. In 1906 the increase in the number of papers coming under this classification made it necessary to divide the contributions into two parts, one including papers on metals and nonmetals except fuels and the other including papers on mineral fuels. In 1915 the year included in the title was changed from the year in which the field work reported in these papers was done to the year of publication, and in consequence there was no volume entitled "Contributions to economic geology, 1914." The subjoined table gives a summary of these bulletins.

United States Geological Survey "Contributions to economic geology."

Date in title.	Date of publication.[a]	Bulletin No.	Date in title.	Date of publication.[a]	Bulletin No.
1902	1903	213	1911, Part I	1913	530
1903	1904	225	Part II	1913	531
1904	1905	260	1912, Part I	1914	540
1905	1906	285	Part II	1914	541
1906, Part I	1907	315	1913, Part I	1915	580
Part II	1907	316	Part II	1915	581
1907, Part I	1908	340	1915, Part I	1916	620
Part II	1909	341	Part II	1916	621
1908, Part I	1909	380	1916, Part I	1917	640
Part II	1910	381	Part II	1917	641
1909, Part I	1910	430	1917, Part I	1918	660
Part II	1911	431	Part II	1918	661
1910, Part I	1911	470			
Part II	1912	471			

[a] The date given is that of the complete volume; beginning with Bulletin 285, the papers have been issued as advance chapters as soon as they were ready.

As the subtitle indicates, the papers included in these volumes are of two classes—(1) short papers giving comparatively detailed descriptions of occurrences that have economic interest but are not of sufficient importance to warrant a more extended description;

(2) preliminary reports on economic investigations the results of which are to be published later in more detailed form. These papers are such only as have a direct economic bearing, all topics of purely scientific interest being excluded.

Brief abstracts of the publications of the year are given in the annual report of the Director. The complete list of Survey publications affords, by means of finding lists of subjects and of authors, further aid in ascertaining the extent of the Survey's work in economic geology.

The reports on work in Alaska have been printed in a separate series since 1904, the volumes so far issued being Bulletins 259, 284, 314, 345, 379, 442, 480, 520, 542, 592, 622, 642, and 662.

NOTES ON THE GEOLOGY AND IRON ORES OF THE CUYUNA DISTRICT, MINNESOTA.

By E. C. Harder and A. W. Johnston.

INTRODUCTION.

Geologic work was done in the Cuyuna iron-ore district during 1914, 1915, and 1916 by the United States Geological Survey in conjunction with the Minnesota Geological Survey. The geologic information concerning the district has been obtained almost entirely from drilling and mining operations, and these cover but a small proportion of the total area of the district. As the development work is constantly progressing and new information is becoming available, it has been deemed advisable to publish a brief preliminary report of the results so far obtained and to delay the publication of a more complete report pending the accumulation of further data. The preliminary report, of which the present paper is an abstract, is being published by the Minnesota Geological Survey; the more complete report will be published by the United States Geological Survey.

In connection with the work in the Cuyuna district it has been considered advantageous to make a study of the rock outcrops in east-central Minnesota, west, south, and east of the district. It was thought probable that the structure and geologic relations of these rocks might throw some additional light on the structure and correlation of the rocks of the Cuyuna range and on their relation to the general structure and correlation of the rocks of the Lake Superior region. Consequently many of the outcrops in Cass, Todd, Morrison, Mille Lacs, Kanabec, Aitkin, Pine, and Carlton counties have been mapped in detail and will be fully described in the final report. Brief descriptions of them are given also in the preliminary report. Much interesting information that has a bearing on the geology of the Cuyuna range has been gained in this work.

GENERAL FEATURES OF THE CUYUNA DISTRICT.

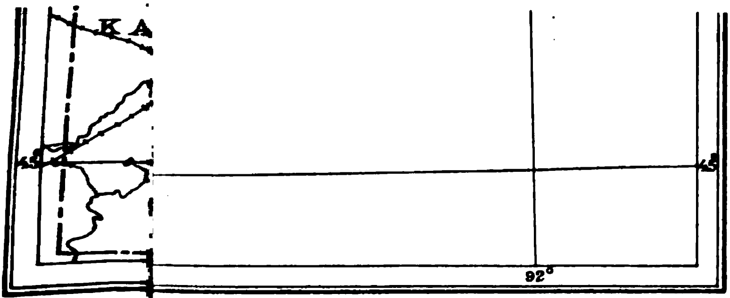
The Cuyuna iron-ore district is near the geographic center of Minnesota, about 90 miles west of Duluth and 55 miles southwest of the western part of the Mesabi district. It extends in a general northeasterly direction, approximately parallel to the Mesabi district, and has a length of about 65 miles. In width it ranges from less than a mile to about 10 miles. Most of the district is in Crow Wing County, but parts of it lie to the northeast in Aitkin County and to the southwest in Morrison County. (See Pl. I.)

The Northern Pacific Railway branch line running from Duluth westward to Staples, to connect with the main line from the Twin Cities to the Pacific coast, passes practically through the entire length of the district, and the main line passes over the southwestern part, near Randall, between Little Falls and Staples. The Cuyuna range branch of the Minneapolis, St. Paul & Sault Ste. Marie Railway connects the eastern and central parts of the district with Duluth and Superior.

The principal part of the Cuyuna iron-bearing belt lies southeast of Mississippi River, to which it is approximately parallel. In the southwestern part of the district, however, the river turns southward and crosses the iron-bearing belt, which continues southwestward beyond it. In the northeastern part of the district, near Aitkin, the iron-bearing belt crosses over to the north side of the river, but it recrosses to the south side within a short distance and continues northeastward to Rice River.

The Cuyuna district, in contrast with some of the other Lake Superior iron-ore districts, does not show any marked topographic relief. It is mainly a region of low, irregular morainic hills interspersed with lakes and extensive swamps and marshes. Outwash plains occupy parts of the district and extend southward from it. Much of the district is under cultivation, especially in the southern part, but in many places the soil is sandy and is covered with a thick second growth of jack pine, poplar, aspen, and locally Norway pine. Much of the rich land also is still uncultivated and supports forests of hardwood. The marshes and swamps contain spruce and tamarack.

The productive part of the Cuyuna district is commonly divided into two ranges—the north range, including the part lying north of the Northern Pacific Railway, and the south range, including the belt lying south of the railway. The north range has a length of about 10 miles and a maximum width of 5 miles. This relatively small area includes most of the productive mines of the district, numbering about 18. The south range is narrow, but it covers a much greater area than the north range and its extensions continue for many miles to the northeast into Aitkin County and to the southwest into Morrison County. One mine on the south range is a steady producer, and four or five others have produced ore intermittently or are in the development stage. The north range is separated from the south range by a belt from 2 to 3 miles wide, underlain mainly by



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YUNA DISTRICT

schist and slate. No iron-bearing rocks of economic importance have been found in this belt, although drilling has been done in it at a number of localities.

The principal towns in the Cuyuna district, named in order from northeast to southwest, are Aitkin, Cuyuna, Deerwood, Crosby, Ironton, Manganese, Iron Mountain, Riverton, Woodrow, Brainerd, and Barrows. All these towns except Aitkin, Deerwood, and Brainerd have been built since the discovery of iron ore in the district. Brainerd, the largest town in the district, was established more than 50 years ago and was at one time the center of the great Minnesota lumber industry. It is now surrounded by a farming community and has a population of about 8,000. Aitkin, the next largest town, has a population of about 2,000. Both Aitkin and Brainerd are on Mississippi River.

The discovery of iron ore in the Cuyuna district was entirely due to the existence of abnormal magnetic attractions in the region. The occurrence of magnetic variations in this district had been known for many years and certain well-defined areas in which they existed had been located, but the iron-bearing formation was not definitely discovered until 1904. In that year iron-bearing rocks with some associated ore were encountered in drilling operations south of Deerwood, and in 1905 ore was also found north of Deerwood, near Rabbit Lake. After these discoveries exploration and drilling were carried on with great vigor throughout the region in which magnetic variations were known to occur, but it was some years before ore in commercial quantity was found. The first ore was shipped from the district in May, 1911, from the Kennedy mine, near Rabbit Lake, at the east end of the north range.

The finding of iron ore in the Cuyuna district soon started speculation concerning a possible connecting belt of iron-bearing rock between this district and the west end of the Mesabi district. Considerable exploration work has been done in the region north and northwest of Aitkin and southwest of Grand Rapids, with the view of finding such a connecting belt. Iron-bearing rocks have been found at a number of places and locally concentrations of ore occur, but these occurrences have not yet been definitely shown to be connected either with the Mesabi district or with the Cuyuna district.

GENERAL GEOLOGY OF MINNESOTA.

The pre-Cambrian complex of the Lake Superior region, consisting of metamorphosed sedimentary and igneous rocks of various kinds, extends westward and southwestward from Lake Superior across Minnesota and forms the basement rock throughout the State. In some places, as in the northeastern part of the State and locally in the southwestern part, the metamorphosed pre-Cambrian rocks are overlain only by a comparatively thin mantle of glacial till; elsewhere they are overlain by flat-lying sediments which in turn are covered by glacial till. Thus in the southeastern part of the State there are beds of Paleozoic and older sediments which are of considerable thickness and extent, and throughout most of the western part of the State there are thin but widespread beds of slightly consolidated Cretaceous rocks.

The sedimentary rocks directly overlying the pre-Cambrian complex in the southeastern part of Minnesota consist of a thick series of red sandstone and shale with associated volcanic clastic rocks,[1] known as the red clastic series and supposed to belong to the red sandstone series of the Keweenawan. They are separated by an unconformity from the underlying older metamorphosed rocks and are similar in lithology and stratigraphic position to upper Keweenawan rocks that are abundantly exposed along the south shore of Lake Superior.[2] Their approximate maximum thickness in southern Minnesota is about 2,250 feet. Fossils have not been found in them.

The Paleozoic rocks, which apparently overlie the red clastic series conformably, range in age from Cambrian to Devonian and consist of interlayered sandstone, limestone, and shale. They are comparatively thin, the entire series, where all the formations are present, having an approximate maximum thickness of less than 2,000 feet.[3]

The Cretaceous rocks that lie on the pre-Cambrian complex throughout most of the western part of the State belong to the Benton and Dakota formations. They consist chiefly of slightly consolidated shale and sandstone, and reach a total maximum thickness of about 500 feet. Locally in the southwestern part of the State they are absent and pre-Cambrian rocks form the bedrock. Outliers of Cretaceous rocks have been found at many places in the eastern part of the State also. Those that occur in the neighborhood of the iron-bearing areas are usually highly ferruginous and in places consist of conglomeratic iron ore.

The pre-Cambrian metamorphosed and intrusive rocks which underlie the sedimentary beds and glacial deposits throughout the State consist of granite and gneiss with which are associated basic igneous rocks of various types and extensive bodies of metamorphosed sediments, such as quartzite, slate, limestone, and many varieties of schist.

In northern Minnesota metamorphosed sediments occur with associated intrusive and extrusive rocks in several unconformable series, ranging in age from Archean to upper Huronian. The Archean rocks are mainly greenstones and green schists classified as Keewatin, into which are intruded masses of granite, syenite, and porphyry classified as Laurentian. The greenstones and green schists are probably in the main altered basic volcanic rocks, both massive and fragmental. Some of them, however, may be of plutonic origin. They have been metamorphosed to such an extent that at present they consist largely of secondary minerals such as chlorite and amphibole, associated with altered feldspar. Where deformation has accompanied metamorphism schistosity is abundantly developed in them. Much of the rock, however, remains in the massive form. Locally, as in the Vermilion iron-ore district, lenses of iron-bearing rock occur in the greenstone; in the Lake of the Woods region and elsewhere slate and graywacke and locally thin beds of limestone are interlayered with schistose and banded greenstone.

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[1] Hall, C. W., Meinzer, O. E., and Fuller, M. L., Geology and underground waters of southern Minnesota: U. S. Geol. Survey Water-Supply Paper 256, pp. 31–49, 1911.

[2] Thwaites, E. T., Sandstones of the Wisconsin coast of Lake Superior: Wisconsin Geol. and Nat. Hist. Survey Bull. 25, 1912.

Van Hise, C. R., and Leith, C. K., Geology of the Lake Superior region: U. S. Geol. Survey Mon. 52, pp. 380 et seq., 1911.

[3] Hall, C. W., Meinzer, O. E., and Fuller, M. L., op. cit., pp. 37–49.

Intrusive granite and syenite of the Laurentian are widely distributed through northern Minnesota, occurring as batholiths, bosses, and dikes in the greenstones and related rocks. Much of the granite and syenite has suffered metamorphism and deformation, so that gneissoid structure is developed in it. Over large areas in this part of the State gneisses are the dominant rocks.

The Huronian rocks of northern Minnesota are of two kinds[1]—an earlier intensely metamorphosed series of slate, graywacke, and conglomerate, usually called lower-middle Huronian, and an upper series, the upper Huronian (Animikie group), consisting of quartzite, iron-bearing rock and slate, which locally, as in the Mesabi district, has suffered but little deformation but which elsewhere, as in the Cuyuna district, has been considerably folded. The lower-middle Huronian metamorphosed sediments are as a rule infolded into the older rocks and occur in irregular areas of somewhat local distribution. The upper Huronian, on the other hand, covers a large part of northeastern and east-central Minnesota and is usually rather regular in its occurrence.

Extensive masses of granite of lower-middle Huronian age are intruded into the lower-middle Huronian metamorphosed sediments as well as into the older Archean rocks. This granite forms the Giants Range, north of the Mesabi iron-ore district. It is difficult to separate from the older Laurentian granite, being distinguishable only by its intrusive relation to lower-middle Huronian rocks.

Besides the Huronian and Archean rocks there are in northeastern and eastern Minnesota several large areas of Keweenawan igneous and sedimentary rocks. Keweenawan rocks consisting of intrusive gabbro and diabase associated with volcanic rocks and some sediments extend along the north shore of Lake Superior from Duluth northeastward their metamorphism and deformation, and (3) younger rocks which lie horizontally on the eroded surfaces of the rocks of the other two classes.

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[1] Van Hise, C. R., and Leith, C. K., op. cit., pp. 118–220.

The age of the various rocks is not definitely known. Because of their metamorphosed and folded state, those of the first class have usually been designated Huronian, and on account of their general relation to the rocks of the Mesabi district and the occurrence of iron-bearing rock in them, it has generally been supposed that they are of the same age as the iron-bearing rocks of the Mesabi district—that is, upper Huronian.[1]

In accordance with this view all the slates, schists, and other metamorphosed rocks in east-central Minnesota have been grouped under the term Virginia slate, which was originally applied to the slate overlying the iron-bearing Biwabik formation in the Mesabi district. This correlation seems reasonable, to judge from the present knowledge of the structure, but as detailed knowledge of the region increases it may be found to be erroneous. It is possible that the metamorphosed rocks of the Cuyuna district and the surrounding region belong at either a higher or a lower horizon than the upper Huronian rocks of the Mesabi district, or it may be that they comprise rocks of several different geologic epochs. It is undoubtedly true that in most areas of pre-Cambrian rocks in the northern United States and Canada, where detailed work has been possible, the occurrence and distribution of the rocks have been shown to be very much more complex than they are at present supposed to be in east-central Minnesota.

Several attempts have recently been made to revise the generally accepted correlation of the pre-Cambrian rocks of the Lake Superior region established by Van Hise and Leith and their coworkers. Although excellent detailed work has undoubtedly been done in the last few years and much valuable information has been obtained, some of which is entirely new, it seems to the writers that it is premature to change radically a correlation based on years of careful field work. The attempted revision of the correlation is largely based on the finding by Allen and Barrett[2] of a series of metamorphosed sediments unconformably overlying the upper Huronian rocks in the eastern part of the Gogebic district in northern Michigan. This series Allen and Barrett propose to classify as upper Huronian, and the existing upper Huronian is to be placed in the middle Huronian.

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[1] Van Hise, C. R., and Leith, C. K., op. cit., pp. 211 et seq.

[2] Allen, R. C., and Barrett, L. P., A revision of the sequence and structure of the pre-Keweenawan formations of the eastern Gogebic iron range of Michigan: Jour. Geology, vol. 23, pp. 689-705, 1915. Allen, R. C., A revision of the correlation of the Huronian group of Michigan and the Lake Superior region: Idem, pp. 705-724.

Using this revised classification of the rocks of the Penokee-Gogebic district as a basis, Allen has reclassified the rocks in most of the other Lake Superior iron-ore districts in a similar manner, with the result that practically all the productive iron-bearing rocks of the Lake Superior region, except those of the Vermilion district, are placed in the middle Huronian. In the Mesabi district the Pokegama quartzite, the iron-bearing Biwabik formation, and the Virginia slate have all been reclassified by Allen as middle Huronian; in the Cuyuna district also the older metamorphosed rocks have been placed in the middle Huronian; and the lower-middle Huronian rocks of the Mesabi and Vermilion districts have been designated lower Huronian.

There is no additional evidence in Minnesota for this revision in the correlation of the rocks of the Lake Superior region, the entire reclassification being based on the finding of the so-called Copps formation stratigraphically above the upper Huronian in the eastern part of the Gogebic district, supported by certain minor evidence afforded by the lithology and distribution of the rocks in some of the other iron ranges of northern Michigan. The writers believe that so important a change in correlation over a wide area as Allen and Barrett suggest should perhaps have a sounder basis.

Detailed work of exceptional value on the lithology and correlation of the iron-bearing Biwabik formation in the Mesabi district has been done during the last few years by Wolff.[1] He has found at certain horizons slaty and conglomeratic zones, some of which have a remarkably wide distribution, running from one end of the district to the other. In general it appears from his work that the iron-bearing formation shows a definite stratigraphic succession that is fairly uniform throughout the district. Besides working on the iron-bearing rocks, Wolff has also made observations on the contact of the Biwabik formation and the overlying Virginia slate. He finds that a limestone layer several feet thick occurs along this contact wherever it has been observed and that at a few localities conglomeratic material is found in the upper part of this limestone layer. Taking the latter fact in conjunction with the phenomenon of the variation in thickness of the Biwabik formation from place to place, as well as the radical change in the character of the sedimentation from iron-bearing sediments to argillaceous clastic sediments, Wolff suggests that there may have been an erosion interval between the deposition of the Biwabik formation and that of the overlying Virginia slate. He hints that such a time break may be of some significance in a revision of the correlation of the rocks of the Lake Superior district but wisely refrains from drawing any sweeping conclusions.

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[1] Wolff, J. F., Recent geologic developments on the Mesabi iron range, Minn.: Am. Inst. Min. Eng. Bull., December, 1916, pp. 1763–1787.

These investigations serve to indicate that by no means the last word has been said in regard to the geology and classification of the rocks of the Lake Superior region. As detailed work continues to be done in the less well-known districts and the stock of information increases, doubtless changes will be made in the correlation of different formations. For the present, however, it seems best to adhere to the generally accepted classification of Van Hise and Leith.

The old metamorphosed rocks of the Cuyuna district, grouped under the term Virginia slate, are principally schists of various kinds associated with beds and lenses of the Deerwood iron-bearing member. Locally quartzite has been found also, and at one or two places limestone is reported to occur. The schists are principally quartzose and argillaceous sericitic schists, probably of sedimentary origin. With these is associated green chloritic schist that appears to be of igneous origin, although the original texture has almost entirely disappeared. Metamorphosed igneous rocks, in which schistosity is but slightly developed, however, and in which igneous textures are still clearly visible, have also been found in drilling operations in different parts of the district.

The rocks of the second class mentioned above, the igneous rocks that are intrusive into the metamorphosed rocks and have themselves not been metamorphosed, are generally supposed to be of Keweenawan age. If the metamorphosed rocks are of upper Huronian age this is a reasonable assumption. These rocks occur as dikes or irregular intrusive masses of different sizes cutting the older rock and in many places causing further metamorphism along the contacts. All rocks of this class so far found in the district are basic or semibasic, such as diabase and diorite, and are usually medium fine grained or porphyritic. Many of them are massive and fresh and have preserved their igneous texture perfectly, but others are considerably altered. In general they are somewhat difficult to distinguish from the nonschistose phases of the metamorphosed igneous rocks associated with the older schists and iron-bearing formation.

Outside of the district, acidic rocks, such as granite and syenite, as well as basic rocks, are intrusive into the older metamorphic rocks. Some of the acidic intrusives occurring south and southeast of the Cuyuna district, near Little Falls and in the Mille Lacs Lake region, are associated with schists into which they appear to be intruded. These schists are supposed to be of the same age as those of the Cuyuna district and are intruded also by basic and semibasic rocks like those in the Cuyuna district. The acidic igneous rock in this region has therefore all been classed as Keweenawan by Van Hise and Leith, although much of it is not associated with schist and presents coarse gneissoid phases that are much more characteristic of the Archean granite than of the Keweenawan acidic rocks. Much of this granite and gneiss which is not definitely known to be intruded into schist may be older than Keweenawan and may belong to the Laurentian or lower-middle Huronian intrusions, but the separation is difficult to make.

The rocks of the third class occur only locally and in minor quantity. They are of two types—(1) horizontal flows of igneous rocks,[1] probably of Keweenawan age, which have been found at one or two places underlying the glacial drift and overlying the metamorphic complex, and (2) isolated patches of ferruginous conglomerate and other sediments, which have been correlated with similar patches of sediments of Cretaceous age in the western part of the Mesabi district. The rocks of the first type may perhaps be correlated with the Keweenawan trap rocks found in the region of St. Croix River in eastern Minnesota, but no outcrops of them have been found in the central part of the State. Cretaceous rocks probably to be assigned to the second type crop out along Mississippi River south of Little Falls and elsewhere in central Minnesota. Most of these rocks are clayey or slightly calcareous, but a few are conglomeratic and ferruginous and resemble the rocks found in drilling operations locally in the Cuyuna district.

STRUCTURE OF THE ROCKS.

The rocks of the Lake Superior region have been subjected to folding at several periods in their history. So far as known, however, the forces causing the deformation in the different periods have been applied in approximately the same direction—that is, from the northwest and southeast—so that the results, as apparent in the rock structure, are superimposed upon one another. The final outcome of these various deformational activities has been that all the pre-Cambrian rocks of the Lake Superior region have been folded into a great complex synclinorium trending approximately northeast.

The Keweenawan rocks have suffered the least folding of all, and form a broad trough with a gently dipping northwest limb and a more steeply dipping southeast limb. The older rocks have been successively more severely deformed, the upper Huronian having many minor folds within the main synclinorium and the lower middle Huronian and Archean being in places so intensely deformed that it is almost impossible to decipher their relation to the general structure of the region. The general strike of the rock bedding, cleavage, and schistosity throughout the Lake Superior region varies between east and northeast. It is this similarity of secondary structures in all the rocks which most strongly points to the conclusion that the deformational movements at different periods have varied but little in direction.

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[1] Zapffe, Carl, The Cuyuna iron-ore district of Minnesota: Brainerd Tribune Suppl., July 1, 1910.

Conforming with the general structure of the Lake Superior region, the rocks of the Cuyuna district are folded into a complex series of northeastward-trending anticlines and synclines.[1] The dip of the limbs of the folds is usually vertical or very steep, and may be either to the southeast or the northwest, though the southeasterly dip predominates. In many places close folding has resulted in producing an approximate parallelism of both limbs of a fold. This is probably the explanation for the great predominance of southeasterly dips in the district in both the north and the south ranges. The pitch of the folds is usually very low, and may be either to the northeast or to the southwest. Pitches in one or the other direction usually predominate in different parts of the district. Thus at the southwest end of the north range the pitch of the folds is in general to the northeast, but along the central part of the north range it is to the southwest. In many places the pitch is so low that the crests of the anticlines are practically horizontal for miles, as is the case locally in the south range. Because of this low pitch of the folds the rock layers appear on the erosion surface as approximately parallel northeastward-trending bands. In some places, where the pitch brings rock layers below the erosion surface, sharp turns occur and the bands double back on themselves. Elsewhere minor drag folds cause local irregularities in their trend.

On account of the lack of exposures and the insufficient drilling and underground development it has not yet been possible to work out the details of the structure. Drag folds and other secondary structural features point to the existence of several major and many minor folds in both the north range and the south range. Ultimately, by means of these features, it may be possible to determine the relationship between the rocks in different parts of the district. The apparent absence of any definite stratigraphic succession, however, is a serious drawback in working out the geologic relations.

The general distribution and structure of the rocks in east-central Minnesota indicate that the Cuyuna district is situated near the axis of the southwestern extension of the Lake Superior synclinorium. The close folding which exists in the district would thus be naturally accounted for, as well as the very gentle folding and relatively slight metamorphism of the rocks along the Mesabi range, which are supposed to be on the north limb of the synclinorium. The south limb is as yet unknown. The extensive masses of granitic rock in the Little Falls, St. Cloud, and Mille Lacs Lake regions may be south of the synclinorium or, as believed by Zapffe,[1] they may be intrusions within it. It is known that some of these granites intrude metamorphosed sediments, but the age of the sediments is not definitely established and they may be older than upper Huronian. If the granite is lower-middle Huronian or Laurentian and represents the basement upon which the metamorphosed sediments of the Cuyuna district rest, then the south limb of the synclinorium may be expected to run northeastward from Little Falls through the northern part of the Mille Lacs Lake region toward Kettle River. On the other hand, if the granite is of later age than the metamorphosed sediments of the Cuyuna district the south limb of the synclinorium may be far to the southeast.

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[1] Van Hise, C. R., and Leith, C. K., op. cit., pp. 620 et seq. Zapffe, Carl, The Cuyuna iron-ore district of Minnesota: Am. Assoc. Adv. Sci. Proc., December meeting 1910. See also Brainerd Tribune Suppl., July 1, 1910.

LITHOLOGY OF THE ROCKS.

OLDER METAMORPHOSED ROCKS.

GENERAL CHARACTER.

The principal constituents of metamorphosed rocks of the Cuyuna district are chloritic, micaceous, and quartzose schists. Associated with these are extensive layers of iron-bearing rock and locally lenses of quartzite and masses of metamorphosed igneous rock. Black carbonaceous slate also occurs in many places, and limestone has been encountered here and there. These rocks are irregularly interlayered with one another. They all have a general northeasterly strike and as a rule dip steeply to the southeast or less commonly to the northwest. On the horizontal surface the different rock layers appear as discontinuous bands of varying width, all more or less parallel.

Up to the present time it has been impossible to work out any definite stratigraphic succession for the metamorphosed rocks of the district. The only horizon markers of any considerable extent are the layers of iron-bearing rock. These, however, are unsatisfactory, for a number of distinct bands of iron-bearing rock run through different parts of the district and it is not yet known whether they are the surface expression of a single layer that has been complexly folded, or whether several different layers and lenses of iron-bearing rock exist at different stratigraphic horizons. The different bands of iron-bearing rock differ in the character of materials which they contain and in the nature of the wall rock which bounds them. This would indicate that they are not portions of the same layer. On the other hand, a single band of iron-bearing rock may show distinct and even abrupt changes in the nature of its constituent materials, both along and across the strike. Thus certain bands may show highly manganiferous ore along one side and ferruginous chert or hematite with only a trace of manganese along the other side. Other bands may consist in one locality almost entirely of red or brown hematite and hematitic or limonitic chert and in another locality largely of black magnetic ore and magnetitic slate. It is thus difficult to correlate the different bands on the basis of lithology.

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[1] Zapffe, Carl, op. cit.

Some geologists believe that perhaps the different bands of iron-bearing rock in the north range may be referred to a single layer, but that the bands in the south range represent a different and probably higher stratigraphic horizon. This belief is based on the fact that the ore and iron-bearing rock in the two ranges present rather distinct lithologic differences. The ore of the south range is usually black or yellow and is associated largely with slaty argillaceous rock, much of which is magnetitic. Ferruginous chert does not occur as abundantly as on the north range, and manganese oxide is present in small amounts only in a few places. The ores of the north range, on the other hand, are usually brown, red, or blue and are abundantly associated with ferruginous chert and only locally with magnetitic slate. In places they contain much manganese oxide, which may be present in distinct bodies or may be disseminated through the iron ore. In view of the facts, however, that much of the iron-bearing rock of the north range is associated with slaty magnetitic rocks and that the manganese oxide is only local in its occurrence and apparently increases in amount toward the north, it does not seem that the lithologic differences noted between the iron-bearing rocks of the north range and south range are sufficient to justify their assignment to separate horizons.

What is true of the layers of iron-bearing rock as horizon markers is also true of the associated rocks, and as these in general are much less continuous and less uniform they are of but little value in this respect. The chloritic schist, which is perhaps the most characteristic of these associated rocks, occurs in lenses which, although of considerable width, are rarely very long. Such lenses occur at several horizons, commonly being interlayered within the iron-bearing formation itself.

Carbonaceous slate is frequently used as a local horizon marker, as it has often been found to occur along the boundary of the iron-bearing beds. However, single layers are rarely continuous for long distances along the strike. On the south range black carbonaceous slate is much more characteristic than on the north range, being so commonly associated with the ore bodies that its presence is considered a good indication for ore.

It might be supposed that quartzite would form a definite stratigraphic unit in this district, as it does in most of the other Lake Superior iron-ore districts. However, in the Cuyuna district quartzite lenses and layers have been encountered only in a few places and it has not yet been possible to determine any relationship between the scattered occurrences.

It is possible that, as exploration work progresses and individual beds of different rocks are traced along the strike, some orderly arrangement of layers may be found to exist. For the present, however, any attempted correlation is bound to be largely speculative.

IRON-BEARING FORMATION AND IRON ORE.

The iron-bearing formation of the Cuyuna district presents a variety of lithologic types. Among the more common rocks composing it are hematitic and limonitic chert and slate, cherty and slaty iron carbonate, siliceous magnetitic slate, amphibole-magnetite rock, jaspilite, dark-blue, red, brown, black, and yellow iron ore, black, red, and brown manganiferous iron ore, green chloritic schist, and dark-red hematitic schist.

Limonitic and hematitic chert are very abundant in the north range, where they compose the principal part of the iron-bearing formation. They usually consist of interlaminated white, pink, or gray chert and hematite or limonite, the chert and iron oxide occurring in alternate layers. The hematite and limonite may be fairly pure or very siliceous. In many places the iron oxide present is rather of the nature of a stain or an impregnation. Thus there are all gradations of ferruginous chert from siliceous iron ore to chert containing only a small percentage of iron oxide. Much of the ferruginous chert, instead of being banded, presents a blotchy appearance, due to the irregular distribution of chert and iron oxide or to the irregular staining of the chert by the iron oxide. The more siliceous iron-stained chert usually shows a more irregular distribution of chert and iron oxide. In many places ferruginous chert shows an even brown or red color throughout, the entire mass of chert being impregnated with iron oxide.

The chert laminae in ferruginous chert are typically fine grained, dense, and flinty, but locally they have suffered partial disintegration and present a fine sugary appearance. When completely disintegrated they break up into fine sand, giving rise to what is known as wash ore. Wash ore is soft ferruginous chert from which the disintegrated chert can be removed by washing while the iron oxide remains behind and becomes concentrated.

The ferruginous chert occurring in the Cuyuna district is very similar to that found in most of the other Lake Superior iron-ore districts except the Mesabi. In all the Michigan and Wisconsin districts the common rock of the iron-bearing formation is a more or less regularly banded ferruginous chert believed by Van Hise and Leith[1] to have been derived by alteration from an original cherty iron-carbonate rock. In the Mesabi district, however, the ferruginous chert is largely of the type known as taconite, a rather massive-bedded cherty rock irregularly speckled with iron oxide which is supposed to have resulted from the oxidation of the ferrous silicate rock greenalite. No taconite or greenalite has been found in the Cuyuna district. It is therefore generally supposed that here, as in most of the other Lake Superior iron-ore districts, the original rock from which the present hematitic and limonitic chert and iron ore have in large part been formed is a banded cherty iron carbonate rock.

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[1] Van Hise, C. R., and Leith, C. K., op. cit., pp. 499–561.

An alternative to the belief of the older geologists that most of the iron-bearing rock of the Lake Superior region was originally deposited as ferrous carbonate or silicate is the view that much of the iron was deposited in the ferric form originally. This view supposes the iron to have been deposited largely as hydrated ferric oxide with colloidal silica and locally with clay. In places, perhaps, thin beds of more or less pure ferric oxide were formed. After the deposition the presence of carbonaceous matter here and there probably caused a partial deoxidation of the ferric oxide and resulted in the formation of local masses of ferrous rock such as iron carbonate or iron silicate. Upon metamorphism these materials were consolidated and in part dehydrated, forming ferruginous chert and slate with local lenses of ore and some bodies of ferrous rock. After the metamorphism had taken place the rocks were subjected to weathering and erosion, which resulted in the formation of additional iron ore by the leaching of silica from the ferruginous chert, as well as in the oxidation of much of the ferrous rock originally present. The main difference between this view and the older one is in the amount of iron originally deposited as ferric oxide, the older view being that very little iron was deposited in the ferric form, the deposition of practically the entire formation occurring under reducing conditions. Thus, according to the older view, the present ferruginous chert, ferruginous slate, and ore have resulted almost entirely from the weathering and leaching by meteoric waters of original rocks containing ferrous carbonate or ferrous silicate.

The evidence afforded by the Cuyuna district on this question is largely in favor of the older view. In the exploratory drill work cherty iron carbonate and associated rocks were encountered below a surface capping of ferruginous chert and iron ore in many parts of the district, and in some of the more recent mining operations such rocks have been encountered in the lower levels in direct continuity along the bedding with the ore, ferruginous chert, and ferruginous slate of the upper levels. In general the gradation from ore at the surface through lean ferruginous chert into ferrous rock below is perhaps more typically illustrated in parts of the

Cuyuna district than in any of the other Lake Superior iron-ore districts.

The cherty iron carbonate of the Cuyuna district, however, differs from the typical cherty iron carbonate rock of the other districts. A number of different varieties occur, some cherty, some slaty, and others highly magnetitic. Most of them contain varying amounts of chert, siderite, and amphibole. With these may be associated argillaceous material, and some varieties contain an abundance of magnetite which is either disseminated through or interlaminated with the other constituents. The cherty iron carbonate generally shows distinct banding and in places fine lamination, the latter being especially characteristic of the slaty varieties, but certain massive argillaceous varieties occur also.

Hematitic and limonitic slates are not as abundant in the district as ferruginous chert but occur locally as beds and lenses interlayered with ferruginous chert or iron ore. They are usually reddish, brownish, or yellowish, and present a thinly laminated appearance. Red hematitic slate is by far the most abundant. It is dark red, soft, and in general finely and regularly laminated. Siliceous slates that show gradation into ferruginous chert occur also. These are thinly laminated but are hard and in places contain thin chert layers. The ferruginous slates represent stages in the deposition of the iron-bearing formation when fine, argillaceous sediment rather than silica was being deposited with the iron. They are generally not slates in the proper sense of the word, as they rarely show slaty cleavage, but are rather indurated ferruginous shales or ferruginous argillites. They are not as abundant in the Cuyuna district as in some of the other iron-ore districts, especially the Mesabi.

The ferruginous slates differ from the hematitic schist described on page 23 in that they are of sedimentary origin, having been deposited with the ferruginous cherts and suffered the same alterations. The hematitic schist, on the other hand, results from the alteration and impregnation with iron oxide of the green chloritic schist, a rock of probable igneous origin, which is commonly associated with the iron-bearing formation.

Cherty and slaty or, more properly, argillaceous iron carbonate rocks, as already mentioned, are believed to be the original rocks from which the iron-bearing formation of the Cuyuna range in its various phases is largely derived. Such rocks have been reported from many parts of the district, having been found in the deep drilling. They are of several different types, with gradational phases between. They vary in composition and texture and range from light to dark green or gray in color. Usually they consist of chert or argillaceous material interlayered or intermixed with amphibole and iron carbonate. Magnetite is a common constituent, and with increasing magnetite and recrystallization of the other constituents these rocks grade into amphibole-magnetite rock and magnetitic slate.

The banding of the cherty and argillaceous iron carbonate rocks is largely due to interlayering of different constituents. The laminae of chert and siderite are usually light gray or greenish; those of argillaceous material and amphibole are darker and with increasing magnetite become almost black. Some varieties of the iron carbonate rock are light gray and consist almost entirely of chert and siderite, which may be intermixed or may be more or less segregated into layers, producing banding. Grains of magnetite occur along lamination planes, making the banding more marked. Other kinds of iron carbonate rock contain considerable amphibole and show interbanding of light-gray and somewhat darker green layers. Still others are very dark gray or green and consist mainly of amphibole and argillaceous material mixed with more or less siderite but containing little or no chert. Such rocks are usually very fine grained and show no marked banding. All these varieties of iron carbonate rock occur interbedded and grade into one another.

The siliceous magnetitic slate and amphibole-magnetite rock are portions of the original iron-bearing formation that have suffered metamorphic alteration and recrystallization. They are banded or laminated rocks, usually very dark colored with a tinge of green, and consist mainly of amphibole with magnetite and some chert or quartz. The fine-grained, finely laminated kinds are known as magnetitic slate and probably contain considerable argillaceous material; the coarser grained and coarsely layered kinds are known as amphibole-magnetite rock. Like ferruginous slate, magnetitic slate rarely, if ever, shows slaty cleavage and might, perhaps, be more properly designated magnetitic argillite. The banding is due to the segregation of the different minerals into layers and also to a difference in the coarseness of crystallization. Thus layers of fairly pure magnetite alternate with layers of amphibole or of quartz and amphibole. Some bands are very fine grained, especially those consisting mainly of magnetite; other bands, as those of amphibole, may be medium coarse grained. The segregation of minerals in the amphibole-magnetite rocks and magnetitic slates is nowhere perfect. Small amounts of magnetite are usually disseminated through the quartz and amphibole layers, and quartz and amphibole are intermixed with magnetite along the borders of magnetite bands.

There is considerable diversity in the composition of these rocks. In some places they consist largely of magnetite and amphibole, in others they contain a considerable amount of silica, either as chert or quartz, with amphibole, but with little magnetite. There is also some irregularity in the texture, such as the thickening or pinching out of laminae. Such irregularities, however, are much less marked than they are in the ferruginous cherts.

The amphibole-magnetite rocks and magnetitic slate of the Cuyuna district differ from the typical amphibole-magnetite rock of other Lake Superior iron-ore districts, such as the Mesabi, Gogebic, and Marquette, in that they are finer grained, more perfectly laminated, and in general contain less quartz and more ferromagnesian minerals. The typical amphibole-magnetite rock of the Cuyuna district consists of alternating fine bands of magnetite and amphibole. That occurring in the eastern part of the Mesabi district, on the other hand, consists of irregular layers of fine-grained magnetite and coarse-grained quartz and amphibole. In the Cuyuna district quartzose and cherty varieties of the amphibole-magnetite rock and magnetitic slate are also common and are characteristic, more especially, of the less highly magnetitic rock.

Jaspilite is of rather rare occurrence in the Cuyuna district, but well-defined beds of it are found in several of the mines. Thus at the Cuyuna Mille Lacs mine both the hard red banded jasper and the specular schistose jasper occur in the southern part of the main ore body, where they are interlayered between typical banded hematitic chert on one side and lean manganiferous iron ore on the other side.

Jaspilite is metamorphosed and recrystallized ferruginous chert. Where the metamorphism has not been very intense a hard dense bright-red rock is formed. This is the more common variety, the crystalline, specular form that results from pronounced recrystallization being of local occurrence. In places in the Cuyuna district there is a very hard siliceous ferruginous chert to which the term jasper is sometimes applied. This rock, however, varies in color from brown or reddish brown to black and is simply a hard, dense form of the ferruginous chert.

The iron ores of the Cuyuna district are inclosed in other iron-bearing rocks. The ore bodies are as a rule roughly tabular in shape, with the longer axes parallel to the bedding of the inclosing rocks. As the beds of rock generally dip steeply, the ore bodies are shown at the surface as bands that extend for considerable distances along the strike of the beds. They range in width to several hundred feet and are usually very long, some of the known ore bodies being more than a mile in length. Some of them are comparatively shallow, extending perhaps to a depth of 200 or 300 feet, where they give way to ferruginous chert, amphibole-magnetite rock, or unaltered iron-bearing rock. Others extend to greater depths, either continuing indirectly downward along the bedding or running diagonally downward parallel to the strike in the form of shoots. The data regarding the depths reached by the ore bodies are still very incomplete. The deepest mining operations at present extend to a depth of about

280 feet below the bedrock surface, and to this depth ore is known to continue uninterruptedly. The exploratory drill work in the district has for the most part been shallow, few holes reaching a depth greater than 700 feet. Ore has been encountered in some of the deeper holes, however, and it is believed that certain ore bodies may reach a considerable depth.

The ore bodies are usually inclosed between walls of ferruginous chert or ferruginous slate. Where chert is the wall rock the contact is usually much more irregular than where slate forms the wall rock. Numerous beds and irregular horses of ferruginous slate and chert occur in the ore bodies. Green chloritic schist and dark-red hematitic schist are also common associates of the iron ore. They may form the wall rock of the ore bodies or they may be interlayered with the ore, more or less parallel to the bedding. Other rocks associated with the ore bodies are amphibole-magnetite rock, magnetitic slate, cherty and slaty iron carbonate rocks, and black carbonaceous slate. These are very common along the south range, where they form the wall rocks of the ore bodies in many places. In the north range the amphibole-magnetite rock and iron carbonate rock more commonly occur underneath ore bodies, representing the deeper, unaltered portions of the iron-bearing formation.

Most of the iron ore occurring in the ore bodies of the Cuyuna district is medium soft, but hard ore is also abundant and is more or less irregularly associated with the soft ore. The Cuyuna ore probably shows a greater variety of texture, composition, and color than the ore from any of the other Lake Superior iron-ore districts. It shows all stages of hydration from pure reddish-blue hematite to ocherous yellow limonite, and both argillaceous and siliceous phases are common. On the north range the ores vary from dark reddish-blue high-grade hematite to reddish and yellowish brown siliceous or argillaceous hematite and limonite, and siliceous and argillaceous manganiferous iron ore is of common occurrence. Locally wash ore is associated with the other ores. On the south range the typical ores are reddish-brown hydrous hematite, dark-brown to black limonite, and yellow ocherous limonite.

The richest ore that has been found in the district is a medium-soft reddish-blue hematite, which occurs at the Croft mine and locally in the Armour, Ironton, and Pennington mines in the north range. Much of this ore is of Bessemer quality, picked samples from the Croft mine analyzing as high as 67 to 68 per cent metallic iron and as low as 0.01 to 0.03 per cent phosphorus. Ore of this grade is of course exceptional, but a large part of the Croft ore body consists of ore of Bessemer quality and will be mined as such. In the other mines no attempt is made to mine the Bessemer ore separately. The common ore in the north range is a medium-soft to hard brown to reddish or bluish-brown hydrated hematite and limonite. Much of this ore is siliceous and grades with increasing silica into ferruginous chert and wash ore. Much of it also is somewhat argillaceous. Ore of this type is shown in the Kennedy, Thompson, Armour, Pennington, and Rowe mines. It is usually found in somewhat irregular, lenticular bodies inclosed in or associated with hematitic and limonitic chert and slate. In places ferruginous chert is interbedded with the ore or occurs in the ore bodies as irregular masses. The character of the ore varies somewhat with the nature of the inclosing rock. Where the wall rock is mainly hematitic slate, as in certain deposits in the southwestern and central parts of the north range, the ore is soft, dark red or bluish red, and usually somewhat argillaceous. On the other hand, ore that is inclosed in ferruginous chert is medium hard, somewhat siliceous, and generally much fractured, so that it breaks up into small blocks. Ore of this class usually ranges in content of metallic iron from 58 or 60 per cent downward, its grade depending on the amount of silica or alumina present. The phosphorus ranges from 0.1 to 0.4 or 0.5 per cent.

Another variety of ore found in the north range is finely laminated brownish-yellow limonite such as occurs in the Mahnomen open pit. Ore of this type, though usually relatively low in silica, is more hydrated than the other ores of the north range. The yellow ocherous limonite ore also is common along the south range, where its occurrence is similar to that of the black limonite ore. Usually it is soft and friable. Though in a few places argillaceous, as a rule it is fairly pure and carries as much as 56 or 57 per cent of metallic iron, which is nearly the theoretical limit for limonite.

The so-called "wash ore" of the Cuyuna district has attracted considerable attention, and two washing plants have been erected to treat it. This ore is simply disintegrated ferruginous chert in which the chert is in the form of extremely fine sand and can readily be washed out, leaving the particles of iron oxide behind. The metallic iron content of the ore may be increased in this manner by 8 to 12 per cent.

The soft black limonite ore is common on the south range but is rarely found on the north range. It is generally associated with amphibole-magnetite rock and magnetitic slate, just as the typical ores of the north range are associated with ferruginous chert and slate. As a rule it is slightly magnetic, owing to the presence of disseminated particles of magnetite. This magnetite, which occurs also in other south-range ores, is presumably similar in origin to the magnetite in the associated amphibole-magnetite rock and magnetitic slate. It is probably residual from original magnetite-bearing rock which has in large part been altered to ore.

Manganese ore and manganiferous iron ore are common in the north range, especially in the northern part. All gradations occur from an almost pure manganese ore with only a few per cent of iron to iron ore with only a fraction of 1 per cent of manganese. The distribution of the ores of different grades is very irregular. Nodules and small bodies of high-grade manganese ore usually occur scattered through low-grade manganiferous iron ore or manganiferous iron-bearing rock, and the latter are themselves irregularly interbedded with other portions of the iron-bearing formation or with schist. A number of manganese minerals occur in these deposits, chief among which are manganite, pyrolusite, psilomelane, and wad. Any of these minerals may compose the nodules or bodies of manganese ore, and in places two or more of them are associated in a single body.

The manganiferous iron ore is usually black or dark brown, and much of it has a yellowish or reddish tinge. The content of manganese commonly ranges from 1 or 2 to 30 or 35 per cent. The ore usually occurs in large bodies, the manganese content of which varies greatly from place to place. Generally a decrease in the percentage of metallic manganese is accompanied by an increase in the percentage of iron, the combined percentage of iron and manganese being fairly constant. As the iron and manganese decrease silica and alumina increase, and the material becomes manganiferous iron-bearing rock. Manganiferous iron ore may be soft or hard. Some forms are dense and massive; others are friable. It is difficult to tell which of the manganese minerals is associated with the hematite or limonite in the manganiferous iron ore. Probably all the manganese oxides are present in different phases of the ore, but manganite appears to predominate in the hard ore and wad and pyrolusite in the soft ore.

The manganiferous iron-bearing rock in which manganese ore and manganiferous iron ore occur in small and large bodies is argillaceous or siliceous. Some varieties of it are very low in manganese, being simply ferruginous chert, ferruginous slate, or their decomposed equivalents; other varieties are irregularly impregnated with small quantities of manganese oxide throughout. In the rocks of both these groups the richer bodies of manganese and manganiferous iron ore are scattered irregularly.

The general distribution of manganiferous material in the iron-bearing belts of the Cuyuna district is also somewhat irregular. As a rule the more northerly belts are richer in manganese. In the south range exploration work thus far has shown the presence of very little manganiferous material. Some beds of the ore-bearing formation, as those on which the Armour No. 1, Armour No. 2, and Thompson mines are situated, have manganiferous iron-bearing rock on the footwall; other beds, such as that on which the Mahnomen open pit is situated, contain manganiferous material along the hanging wall. In still other localities manganiferous iron-bearing rock and ore may be interbedded with nonmanganiferous iron-bearing rock. Thus there are all variations in the occurrence of the manganiferous material.

The green and gray chloritic schist and the dark-red hematitic schist do not belong to the iron-bearing formation proper but are rather rocks that have become associated with it. They usually occur as small lenses within the layers of the iron-bearing formation or they may bound such layers on each side. The dark-red hematitic schist usually occurs along the borders of such lenses, where they are in contact with iron-bearing rock or iron ore and have become impregnated with hematite for varying distances from the contact; the green or gray chloritic schist occurs in the center of such lenses or forms entire layers where they are not in contact with iron-bearing rock.

It is believed that the chloritic schist represents original masses of basic igneous rock that were intruded as sills into the iron-bearing formation and associated sedimentary rocks while these were still largely in an unmetamorphosed condition. Some of it may be of volcanic origin, having been formed as local, irregular flows. Subsequent metamorphism and deformation affected igneous rocks and sediments alike.

SCHIST, SLATE, QUARTZITE, AND IGNEOUS ROCKS.

The beds of iron-bearing rock, practically throughout the Cuyuna district, are inclosed between layers of schist or slate. Generally the schist or slate on one side of the iron-bearing rock is identical with that on the other side. Locally, however, the rocks forming the two walls present marked differences, but such differences are rarely constant over large areas.

A number of distinct varieties of schist and slate are found in the Cuyuna district, among which are white, light-greenish, or light-brownish quartzose sericitic schist or slate; gray, finely micaceous schist or phyllite; dark-green or gray chloritic schist, commonly micaceous and locally quartzose, as already described; dark-red hematite schist or slate, which may be derived from any of the varieties above mentioned by impregnation with hematite; and black carbonaceous slate, generally containing more or less pyrite.

The distribution of these various schists and slates is irregular, but some are more abundant in one locality and others elsewhere. Thus quartzose sericitic schist is especially abundant in the region lying south of the north range, chloritic schist is very common in association with the iron-bearing belts running from Riverton northeastward to Crosby and Cuyuna, and black carbonaceous slate is conspicuous locally in the northeastern part of the south range.

Although most of the slate and schist of the Cuyuna district are undoubtedly of sedimentary origin, there are certain kinds, as the green chloritic schist, which in their occurrence and relation to the associated rocks strongly suggest an igneous origin. Much of the chloritic schist occurs in comparatively short, thick lenses which are interlayered with other rocks without any apparent order or regularity, although they practically always run parallel to the bedding of the inclosing rocks. The chloritic schist rarely shows lamination or other sedimentary characteristics, and its contact with the associated rocks is sharp. Its chemical and mineral composition has not yet been studied in sufficient detail to allow its definite classification, but indications point toward an igneous origin for much of it.

Most of the light-colored quartzose sericitic schist or slate is very siliceous, and some of it might be termed schistose sericitic quartzite. The gray phyllite, on the other hand, is usually very fine grained and silky in texture and rarely contains much quartz.

Quartzite has been reported as occurring in several parts of the district, notably in the northeastern portion of the south range and near the southwest end of the north range. In the latter locality beds of typical fine-grained vitreous quartzite have been encountered in drilling operations along a belt more than a mile in length, beyond which it seems to disappear in the schist areas. Locally iron-bearing rock and black slate are associated with it, but in general chloritic and micaceous schists occur on both sides of the quartzite belt. In the northeastern part of the south range quartzite has also been found by drilling in a number of localities, especially in the neighborhood of Cedar Lake. At Dam Lake, about 10 or 12 miles east of the Cedar Lake region, quartzite crops out, and there may be some connection between the rocks of the two regions.

Igneous rocks in which the original constituents have been largely altered and which have suffered considerable deformation locally have been encountered in drilling operations in different parts of the district. Most of them seem to have been originally of a semibasic character and now consist mainly of chlorite. Some still show the original igneous textures; others have been rendered schistose and grade into chloritic schist. Gradations have been found between the schistose and nonschistose varieties.

These rocks are believed to be of approximately the same age as the associated metamorphosed sediments, namely, upper Huronian. The less schistose varieties are usually medium to fine grained. In comparatively fresh samples they are difficult to distinguish from the later igneous intrusive rocks, which are believed to be of Keweenawan age. Of the many bodies of igneous rock found in the district very few can be definitely classified with the earlier or the later group. The relations can be determined only by a careful study of the shape of the igneous rock masses, of the degree of metamorphism which they have suffered, and of their relation to the inclosing rocks.

The form of the masses of igneous rock associated with the metamorphosed sediments has rarely been determined by the drilling, although a few of the masses have been found to be irregularly interlayered with rocks of sedimentary origin. Probably many of them represent intrusions, but some have textures that resemble those of extrusive igneous rocks. In general, however, the alteration has progressed to such an extent that the original character is not ascertainable.

LATER INTRUSIVE ROCKS.

Later intrusive rocks which are believed to be of Keweenawan age and which have themselves suffered little or no deformation or dynamic metamorphism are known to occur in many parts of the district. They are practically all basic or semibasic and are of the type usually classed as greenstones, including diorite, diabase, gabbro, and perhaps more basic varieties. Most of them are fine-grained dark-green rocks of granular or ophitic texture, such as occur at the Barrows mine. At one or two localities, as at the Adams mine, a porphyritic variety has been encountered. Many of these intrusive rocks have been altered so that at present they consist mainly of chlorite and decomposed feldspar.

The shape of most of the intrusive bodies is not known, as drilling has been conducted so as to avoid them rather than to outline them.[1] Some are known to be in the form of dikes; others are irregular.

The metamorphic effect of the intrusion along their contact with the older rocks is in most places clearly noticeable. Where the igneous rocks have been intruded into the original iron-bearing formation they have usually produced a recrystallization of the chert into quartz and of lime, magnesia, and other constituents into amphibole. The iron oxide is in many places altered to magnetite. Thus typical magnetitic slate and amphibole-magnetite rock have been developed under the action of intrusions. Whether or not most of these varieties of rock in the district have been produced in this manner or whether they were more generally formed during the deformation is not known. Doubtless the intrusions were effective wherever they occurred, but from present indications they do not appear to have been sufficiently widespread to account for much of the metamorphism.

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[1] Zapffe, Carl, The Cuyuna iron-ore district of Minnesota: Brainerd Tribune Suppl., July 1, 1911.

LATER VOLCANIC AND SEDIMENTARY ROCKS.

Volcanic rocks that lie on the eroded surface of the older rocks are reported by Van Hise and Leith[1] to occur at several localities a short distance south and southwest of Brainerd and also about 6 miles east of Brainerd. They are said to be acidic and to have amygdaloidal texture. The beds are as much as 25 feet in thickness and seem to occupy depressions in the underlying rock surface.[2] These volcanic rocks are believed to be of Keweenawan age.

Isolated patches of sediments lying in horizontal beds on the eroded surface of the iron-bearing formation, schist, and associated rocks have been encountered in drilling and mining operations at a number of localities in the Cuyuna district. These rocks are believed to be of Cretaceous age, because of their similarity to isolated patches of Cretaceous rocks in the Mesabi district. Cretaceous rock that bears a similar relation to the underlying metamorphosed rocks also crops out at several points southwest of the district. In the Cuyuna district proper this rock is a ferruginous conglomerate, consisting of small pebbles of iron-bearing and other rocks in a slaty matrix.[2] Outside of the district the Cretaceous beds consist mainly of sandy and calcareous clay.

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[1] Van Hise, C. R., and Leith, C. K., op. cit., p. 215.

[2] Zapffe, Carl, op. cit.

NOTES ON THE GREENSAND DEPOSITS OF THE EASTERN UNITED STATES.

By George H. Ashley.

INTRODUCTION.

The United States has recently experienced a serious shortage of potash as a result of the shutting off of foreign supplies, and this has led to a vigorous search for new sources of supply in this country and for possible methods of utilizing mineral deposits containing potash. Prominent among these efforts have been the search for deposits of potash salts or potash-containing waters; attempts to utilize the potash of certain plants, such as the kelp of the Pacific coast and the sagebrush of the arid plains; experiments in obtaining potash from the feldspar and other minerals contained in rocks; and the search for material having a sufficiently high content of potash to warrant its commercial exploitation.

Potash is exceedingly abundant in the earth's crust, but usually forms only a small percentage of the rock containing it. Most granites, for example,[1] contain 4 to 8 per cent of potash, and a few of the nephelite and leucite rocks contain over 9 per cent of potash. Many of the rhyolites, porphyries, trachytes, syenites, monzonites, and basalts contain more than 5 per cent of potash. Some minerals, such as sylvite (52.4 potassium) and niter (46.5 potash), contain more than 20 per cent, theoretically, of potash or of potassium, but these minerals are relatively rare in this country and have not yet been found in quantities large enough to be of commercial interest. A few other minerals, such as leucite, alunite, orthoclase, muscovite, biotite, and lepidolite, contain 4 to 16 per cent of potash, averaging about 8 per cent. These are the minerals for which special search has been made. At least one large deposit of leucite-bearing rock averaging about 10 per cent of potash is known in Wyoming, and a claim has been filed on it. Small but workable deposits of alunite, carrying 7 to 11 per cent of potash, have been found in Utah and adjoining States. Small deposits of sericite (muscovite) schist, carrying 5 to 8 per cent of potash, are known in Georgia and the

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[1] Clarke, F. W., The data of geochemistry, 3d ed.: U. S. Geol. Survey Bull. 616, pp. 433 et seq., 1916.

Carolinas. The other minerals mentioned are abundant but are commonly scattered through the rocks as isolated crystals or occur as thin veins or stringers, so that though selected specimens may yield 10 per cent or more of potash, the quantity of such minerals in any body so far known that will maintain an average that high is relatively insignificant.

In their extent and availability these resources of potash-bearing minerals or rocks present a strong contrast to the greensands of the Eastern States, which underlie the surface of hundreds if not thousands of square miles within reach of the steam shovel, and which range in thickness from a few feet to 30 feet and carry 5 to 7 per cent of potash. As a cubic foot of greensand weighs about 90 pounds and (if 7 per cent material) contains 6.3 pounds of potash, a square mile of sand 1 foot thick will yield 78,000 tons of potash. A 20-foot bed that covers a square mile should yield 1,500,000 tons of potash; a 20-foot bed of 5 per cent greensand should yield 1,000,000 tons to the square mile and should also carry about 2,000,000 tons of iron, and possibly 500,000 tons of phosphoric acid. The figures given apply to the best sands only, but if the samples taken indicate the character of the sand throughout the full thickness of the bed there are many square miles of greensand containing 7 per cent of potash and perhaps hundreds of square miles containing 4 or 5 per cent. In view of the possible ease of mining these sands they would seem to offer an adequate source of potash for perhaps several hundred years, provided a cheap method of extracting the potash can be found.

The object of this paper is to place before chemical engineers and others succinct information as to the location and extent of easily accessible greensand deposits in the Eastern States and their content of potash, and thus to provide an answer for many inquiries made of the United States Geological Survey. The paper brings together the results of analyses of samples of greensand that were collected by W. C. Phalen and the writer and analyzed in the chemical laboratory of the United States Geological Survey by W. B. Hicks and R. K. Bailey and gives notes on the occurrence and extent of the beds sampled. It will be noted that the analyses do not substantiate many older analyses of glauconite, the potash-bearing mineral in greensand, which gave 11 and 12 or even 14.5 per cent of potash. All modern analyses indicate that glauconite contains only 7 to 8 per cent of potash.

The samples were taken from deposits that lie near transportation lines, either rail or water, and that could be handled cheaply, in large quantities, either by the steam shovel or dredge or other mechanical means. These limitations to the study were set in the belief that the demand for potash is urgent and possibly only temporary, and that what is immediately desired is rather information as to the best and most available deposits for possible utilization than a comprehensive report that would be of value in the development of the industry.

After a brief review of the available information concerning the greensand deposits of the eastern United States, either published or unpublished, a number of the most promising deposits were selected for study. When the selection had been made Mr. Phalen visited areas in New Jersey, and the writer visited areas in Delaware, Maryland, Virginia, North Carolina, Tennessee, and Arkansas.

In general, the results show that the best and most available deposits are in New Jersey and Delaware, samples from which yielded from 3.50 to 7.15 per cent of potash, the highest percentages coming from deposits in New Jersey. The samples from Maryland yielded 4.45 per cent or less; the samples from Virginia, which contained much lime, yielded 2 to 2.50 per cent; those from North Carolina 2.96 or less, and those from Arkansas 4.90 per cent or less. No glauconite sand was found in Tennessee in the area from which it had been reported by Troost.[1] Since the above was written it has been learned that a little greensand containing not over 3 per cent of potash has been found by Mr. Bruce Wade in McNairy County, Tenn., at the foot of a hill west of Adamsville.

The deposits at these localities are ample to supply any immediate need. Most of those in New Jersey and Delaware are 20 feet or more thick and in many places the thickness of the overburden is less than that of the bed. The practical question therefore is whether these greensands can be used commercially.

COMPOSITION OF GREENSAND.

The term greensand as here used is applied to an unconsolidated sandy deposit containing glauconite. Under the magnifying glass the best greensand appears to be composed entirely of grains of glauconite, less than 1 per cent being grains of quartz sand. More commonly it includes a larger proportion of quartz sand, amounting to one-half or more of the whole. Sand that is composed mainly of grains of glauconite is dark green to light green and becomes darker or almost black when wet. If the proportion of quartz sand is large the sand has a characteristic "pepper and salt" appearance, with only a greenish tinge, and may grade into ordinary yellow or white sand as the proportion of glauconite decreases. In fresh glauconite the grains are light green but a little weathering generally produces a dark coating on them, making them almost black. Such grains, however, appear green when broken. The grains of glauconite are fairly soft and can readily be broken by the finger nail. The size of the grains differs in different deposits. In some deposits more than 85 per cent of the glauconite will go through a 100-mesh sieve; in others one-half or more is caught on a 60 or 80 mesh sieve. In general the grains range from one-fortieth to one one-hundredth of an inch in diameter or less. In some samples the grains of sand are about as large as the grains of glauconite; in others the two differ greatly in size. The following table shows these differences:

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[1] Troost, Gerard, Seventh report of the geological survey of Tennessee, p. 30, 1844.

Results of sifting two samples of greensand from Maryland.

[Grains counted on cross-section paper.]

Mesh of screen.	1		2	
	Quartz.	Glauconite.	Quartz.	Glauconite.
On 10	0	0	0	0
On 30	0	0	22	10
On 60	400	346	979	437
On 80	369	402	224	325
On 100	381	527	44	358
Through 100	262	677	8	235

1. Sample 36, Marlboro, Md.
2. Sample 29, Severn River, Md.

Other deposits show an even more striking difference, which is illustrated by a comparison of greensand from Aquia Creek, Va., with that from Birmingham, N. J.

Results of sifting two samples of greensand from Virginia and New Jersey.

[Percentages.]

Mesh of screen.	Aquia Creek, Va.	Birmingham, N. J.
On 30	0	5
On 60	2	90
On 80	3	3
On 100	10	2
Through 100	85	0

Many deposits of greensand contain, in addition to the glauconite and quartz, more or less calcite, commonly in the form of shells or fragments of shells or as cement derived from shells, and a little clay or other fine material, and some deposits contain a little iron phosphate. Microscopic study would probably reveal particles of undecayed feldspar and other minerals, for a good hand lens shows that a few samples contain a small amount of very fine feldspathic material. The greensand in many southern deposits contains an appreciable amount of mica. Glauconite is a silicate of iron and potassium. The following analyses of glauconite, given by Dana,[1] show its general composition:

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[1] System of mineralogy, 6th ed., p. 468, 1892.

Analyses of glauconite.

	1	2	3	4	5	6	7	8	9	10	11
Silica	49.42	51.24	49.76	50.62	50.42	46.91	49.09	46.90	52.86	50.70	46.58
Alumina	10.23	12.22	8.18	3.80	4.79	7.04	15.21	4.06	7.08	8.03	11.45
Ferric oxide	16.01	13.44	16.00	21.03	19.90	23.06	10.56	27.09	7.20	22.50	......
Ferrous oxide	3.00	3.06	3.77	6.02	5.96	2.64	3.06	3.60	19.48		20.61
Magnesia	3.78	3.93	3.97	[a] .57	2.28	4.40	2.65	.70	2.90	2.16	1.27
Lime	.31	.10	.41	[a] .54	3.21	2.95	.55	.20	Trace.	1.11	2.49
Potash	7.91	7.50	7.57	7.14	7.87	7.31	6.05	6.16	2.23	5.80	6.96
Soda	.26	.31	.52	....	.21	.91	1.21	1.28	Trace.	.75	.98
Water	8.08	8.20	9.82	9.14	5.28	4.71	11.64	9.25	8.43	8.95	9.66
Insoluble material	.80	......	......	......	......	......	......	......	......	......	......
	99.80	100.00	100.00	99.86	99.92	99.93	100.02	99.24	100.18	100.00	100.00

[a] Carbonates.

1. Swir River, Russia. Kupffer, A., Jahresb. Chemie, 1870, p. 1307.
2. Ontika, Russia. Kupffer, A., idem.
3. Grodno Valley, Russia. Kupffer, A., idem.
4. Havre, France. Haushofer, K., Jour. prakt. Chemie, vol. 102, p. 38, 1866.
5. Antwerp, Belgium. Dewalque, F., Soc. géol. Belgique Annales, vol. 2, p. 3, 1875.
6. Gozzo Island, Mediterranean Sea. Bamberger, E., Min. pet. Mitt., p. 271, 1877.
7. Ashgrove, near Elgin, Scotland. Heddle, M. F., Roy. Soc. Edinburgh Trans., vol. 29, p. 79, 1879.
8. Agulhas Bank, Indian Ocean. Gumbel, C. W., K.-bayer. Akad. Wiss. Sitzungsb., vol. 16, p. 417, 1886.
9. French Creek, Pa. Knerr, E. B., and Schoenfeld, J., Am. Chem. Jour., vol. 6, p. 412, 1884.
10. New Jersey. Hunt, T. S., Canada Geol. Survey [Fifteenth] Rept. Progress, pp. 486–488, 1863.
11. Red Bird, Miss. Hunt, T. S., idem.

At a few places the sand is so fine grained as to have the appearance of a green or black clay. One such deposit, from Silver Run, Del., appeared on analysis to contain almost as much potash as pure glauconite.

The following table gives the results of a number of tests made by G. H. Cook.[1] In these tests the clay was removed by stirring in water and decanting. Afterward the washed sand was dried, the quartz sifted out or picked out by hand, and the two parts weighed.

Results of sifting and washing New Jersey greensands.

Locality.	Glauconite.	Clay, etc.	Quartz.
Lower marl bed.			
Marlboro, Monmouth County	58.4	33.6	6.6
Manalapan, Monmouth County	75	25	....
Do	65	32.5	2.5
Perrineville, Monmouth County	52.5	28.8	18.7
Marshallville, Salem County	40.8	32.0	27.2
Scull town, Salem County	25.6	36.0	38.4
Middle marl bed.			
Tinton Falls, Monmouth County	82.0	17.2	.8
Blue Ball, Monmouth County	81.2	17.2	1.6
Do	84.2	15.8	....
Pemberton, Burlington County	90.3	9.8	1.9
Medford, Burlington County	88.5	11.5	....
Inskips Bridge, Burlington County	71.4	28.5	....
White House, Camden County	77.3	21.1	....
Barnsboro, Gloucester County	91.3	7.8	.9
Hurffville, Gloucester County	89.0	11.0	....
Blackwood, Camden County	71.1	28.9	....
Mullica Hill, Gloucester County	86.6	12.5	.9
Woodstown, Salem County	74.3	21.8	3.9
Upper marl bed.			
Vincentown, Burlington County	67.6	28.8	3.6
Clementon, Camden County	16.6	33.6	49.8

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[1] Cook, G. H., Geology of New Jersey, pp. 277 et seq., 1868.

In connection with a study of the greensands of New Jersey, Mr. Cook made a chemical study of the green grains from a number of beds, the glauconite having been carefully picked out by hand:

Analyses of glauconite grains in New Jersey greensands.[a]

	1	2	3	4	5	6	7
Silica	38.50	42.80	45.85	47.10	45.51	50.01	41.72
Ferrous oxide	4.26	3.72	2.98	3.71	3.84	3.84	3.02
Ferric oxide	20.96	17.42	17.11	16.80	19.02	19.00	14.96
Alumina	6.40	6.02	7.88	5.72	7.96	7.36	5.92
Lime	1.06	2.01	1.21	1.97	3.84	.31	8.02
Magnesia	2.13	2.04	2.51	2.88	2.46	2.86	2.93
Potash	8.19	7.99	8.08	7.01	6.74	7.37	6.06
Sulphuric acid	.38	.34	.27	.72	1.12	.43	1.00
Phosphoric acid	1.15	1.40	1.72	1.02	.99	.62	7.35
Water at 100° C.	6.02	4.07	3.26	[b]4.76	.56	.00	1.38
Water above 100° C.	3.80	3.91	4.85	[b]4.15	7.38	7.74	6.30
Quartz	7.70	6.99	4.30	4.10	.85	.40	.90
	100.55	98.68	100.11	99.97	100.29	98.98	99.63

[a] Cook, G. H., Geology of New Jersey, pp. 280–281, 1868: Analyses 1–4 by J. C. Smock; analyses 5–7 by Julius Koch.

[b] Includes carbon dioxide.

1. "Clay marl," Matawan, Monmouth County.
2. "Lower marl bed," Marlboro, Monmouth County.
3. "Middle marl bed," Blackwood, Camden County.
4. "Upper marl bed," Squankum, Monmouth County.
5. "Lower marl bed," Cream Ridge, Monmouth County.
6. "Middle marl bed," White Horse, Camden County.
7. "Upper marl bed," Squankum, Monmouth County.

As the analyses showed some quartz, lime, and phosphoric and sulphuric acids, which Mr. Cook believed formed no part of the glauconite, the analyses were recomputed so as to exclude those substances, as follows:

Recalculated analyses of glauconite grains in New Jersey greensands.[a]

[Numbers assigned to columns correspond to those in preceding table.]

	1	2	3	4	5	6	7
Silica	42.64	48.63	49.15	51.11	48.97	50.93	51.53
Ferrous oxide	4.71	4.23	3.21	4.03	4.13	3.90	3.73
Ferric oxide	23.22	19.80	18.48	18.23	20.46	19.35	18.47
Alumina	7.09	6.84	8.51	6.21	8.56	7.50	7.32
Magnesia	2.36	2.32	2.79	3.14	2.64	2.91	3.62
Potash	9.07	9.08	8.73	7.60	7.26	7.50	7.49
Water at 100° C.	6.66	4.62	3.52	5.16	7.94	7.88	7.81
Water above 100° C.	4.21	4.43	5.22	4.50			
	100.00	100.00	100.00	100.00	100.00	100.00	100.00

[a] Cook, G. H., Geology of New Jersey, p. 281, 1868. Analyses 1–4 by J. C. Smock; analyses 5–7 by Julius Koch.

From all these analyses the author has derived the following table showing approximately the composition of glauconite:

Approximate composition of glauconite.

Silica	50
Ferrous oxide	4
Ferric oxide	19
Alumina	7.5
Magnesia	3
Potash	7.5
Water	8.5
Soda and lime	.5
	100.0

Roughly, glauconite consists of one-half silica, one-fourth iron oxides, one-tenth aluminum and magnesium oxides, one-sixth potash, water, and other substances, the potash forming about 1 part in 13.

If this analysis shows the maximum percentage of potash in glauconite, it is obvious that greensand, even if it is entirely glauconite, can hardly run over 7 or 8 per cent potash. As already mentioned, the best greensands of New Jersey appear to be almost entirely glauconite and on analysis yield 6.40 to 7.15 per cent of potash. In order to test the matter further the writer made an electromagnetic separation of the glauconite grains from sample 36, repeating the process twelve times in order to procure glauconite grains that should be as nearly pure as possible. This material, on analysis, gave 7.05 per cent of potash. If, therefore, a greensand, on examination under a hand lens, appears to be one-half quartz it probably contains no more than 3.5 to 4 per cent of potash. In the particular sample used in the experiment just cited, however, though the sample appeared to be fully one-half quartz, the analysis of the sample as a whole gave 4.48 per cent of potash. The unexpectedly large percentage of potash in this sample indicates that too much reliance must not be placed on a sight test, even though it is based on relations so obvious as those described.

ORIGIN AND NATURE OF GREENSAND.

The origin of greensand is still somewhat in doubt, but there is good reason for believing that it is a product of the alteration of clay or feldspar, particularly clay. The steps assumed by Murray and Irvine[1] are, first, the formation of iron sulphide in sea water in the presence of decomposing vegetable matter and, second, the replacement of the aluminum of the clay by this iron, resulting in a compound that combines with the potash in sea water to form glauconite, the potash in the sea water having been derived from potash feldspars, mica, and other potash-bearing minerals that are brought into the sea. Some water also enters into the glauconite molecule. According to Murray and Renard,[1] the sulphates in sea water act on the iron in mud or clay in the presence of organic matter, producing iron sulphide, which later oxidizes to the hydroxide. At the same time the alumina is removed from the clay by solution, and colloidal silica is liberated, which reacts upon the ferric hydroxide in the presence of potassium salts extracted from the adjacent minerals, the reaction forming glauconite.

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[1] Collet, L. W., Les dépôts marins, p. 169, Paris, 1908. See also Murray, John, and Irvine, Robert, On the chemical changes which take place in the composition of the sea water associated with blue muds on the floor of the ocean. Roy. Soc. Edinburgh Trans., vol. 27, pt. 3, 1893.

As a consequence of variations in the conditions under which glauconite is formed the process of formation does not appear to be very uniform or to produce a single definite compound, for the alumina may not be completely removed and the potassium may be in part replaced by other bases. If the glauconite were pure and had the formula suggested by Dana, $Fe''KSi_2O_6+3H_2O$, it should contain 13 per cent of potash. As a matter of fact, the analyses quoted indicate that some of the potassium is always replaced by other bases.

The most common type of glauconite consists of minute botryoidal pellets whose forms are due, apparently, to the fact that the clay from which they were derived occupied cavities in minute shells. The pellets in another type are round and smooth, as if they had been derived by erosion and redeposition from a deposit of the first type. A third type, which includes glauconite stains and the grains that fill crevices and cavities, may be due in part to the alteration of grains of feldspar.

Glauconite is found in deposits on the sea bottom at depths ranging from about 300 feet to 2 miles.

Recently formed glauconite is well described and illustrated in the report of the *Challenger* expedition.[2] Some of the deposits found by that expedition were almost pure glauconite. Most of the deposits found, however, contained from 40 to 50 per cent of foraminiferous and other calcitic shells. The grains of recent glauconite rarely if ever exceed 1 millimeter in diameter, and are typically rounded or mammillated, hard, and black or dark green. The surface of some of the grains is dull, that of others is shiny. Many of the grains have vaguely the form and appearance of Foraminifera and other organisms. Mixed with these typical grains are many pale-green particles that have the distinct impress of calcareous shells, many being obviously internal casts.

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[1] Murray, J., and Renard, A. F., *Challenger* Rept., Deep-sea deposits, p. 389, 1891.

[2] Idem, pp. 378 et seq.

To those who are interested in the origin and nature of the glauconite in greensand a recent paper by M. I. Goldman[1] will be of interest. Reference should also be made to Clarke's "Data of geochemistry,"[2] which cites other works, and to the earlier papers of Collet[3] and Thoulet.[4]

METHOD OF SAMPLING.

In obtaining the samples of greensand the endeavor was made to see that they represented the average material at the places where they were taken. The samples from New Jersey, obtained by Mr. Phalen, were taken with a soil auger that reached a depth of 12 feet. Most of the samples were taken in old pits. The auger was started at the top of the deposit and driven at an angle so as to cut downward through the deposit and, at the same time, to reach as far as possible from the exposed face. The material brought out by the auger formed the sample.

The samples taken by the writer were cut from the deposits with an army adz such as is used in digging trenches. In the steepest and freshest face of a deposit (mostly in stream or road cuttings) a vertical trench 6 to 10 inches wide was dug to a depth of 3 feet or less and to a length that depended on the thickness of the deposit or on the thickness of the part of the deposit that appeared to be of uniform quality. Where different parts of the deposit appeared to be of different grades, two or more cuttings were made, so as to procure separate samples for analyses. Then a cut was made 3 inches wide and 1 to 2 inches deep for the whole length of the trench, and the material cut off was caught on oilcloth, mixed, and quartered down to make about a 1-pound sample, in about the same way that a sample of coal is taken. By making a series of cuts it was hoped to detect any enrichment that might have occurred and to obtain general information that might be of value in a study of these deposits. David White has suggested that the leaching of a deposit at the surface might enrich parts of it that lay at a lower level. At one or two places the top of a deposit seemed to be slightly richer than the lower part. At other places the proportion of glauconite manifestly increased from above downward. On the whole, the evidence and the analyses do not indicate such enrichment. A few samples were taken to study the effect of weathering, either by comparing the analyses of samples cut at the face of the trench, where the deposit was weathered to red or brown, and at the back of the trench, where the material was still green and apparently unweathered; or by comparing the analyses of samples cut at the top of a bank, where the greensand made the surface soil, and lower in the bank, where the greensand appeared unweathered. (See analyses of samples 31, 32, 51, 52, and 53.)

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[1] Goldman, M. I., The petrography and genesis of the sediments of the Upper Cretaceous of Maryland: Maryland Geol. Survey, Upper Cretaceous, pp. 111–182, 1916.

[2] Clarke, F. W., The data of geochemistry, 3d ed.: U. S. Geol. Survey Bull. 616, pp. 516 et seq., 1916.

[3] Collet, L. W., Les dépôts marins, pp. 132–194, 303–306, Paris, 1908.

[4] Thoulet, M. J., Étude bathylithologique des côtes du golfe du Lion: Inst. océanographique Annales, vol. 4, No. 6, pp. 62 et seq., Paris, 1912.

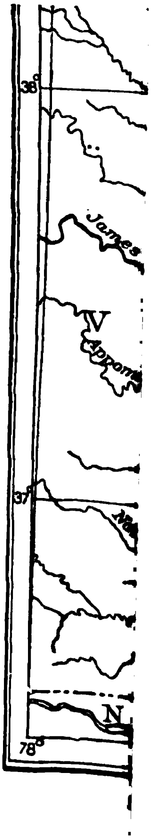
GEOLOGIC OCCURRENCE OF THE GREENSANDS.

The unconsolidated greensands of the northern Atlantic States are found in the Aquia and Shark River formations of the Eocene and in the Manasquan, Rancocas, and Monmouth formations of the Cretaceous. The following table shows the geologic age and thickness of these formations in New Jersey, Delaware, and Maryland:

Principal greensand-bearing formations of New Jersey, Delaware, and Maryland.

Age.	New Jersey.	Delaware.	Maryland.
Eocene.	Shark River marl, from a thin film to 11 feet thick.	Aquia formation, 35 feet thick.	Nanjemoy formation: Woodstock greensand marl member, 70 feet thick. Potapaco clay member, 71 feet thick. Aquia formation: Paspotansa greensand marl member, 47 feet thick. Piscataway indurated marl member, 69+ feet thick.
Upper Cretaceous.	Manasquan formation, 25 feet thick.		
	Rancocas group: Vincentown sand, 25-70 feet thick. Hornerstown marl, 30 feet thick.	Rancocas formation, 20 feet thick.	Rancocas formation, a few feet thick (?)
	Monmouth group: Redbank sand, from a thin film to 100 feet thick, including Tinton sand member, 10-20 feet thick. Navesink marl, 25-40 feet thick. Mount Laurel sand, 5-60 feet thick.	Monmouth formation, 80 feet thick.	Monmouth formation; a thin film at the south; increases to 100 feet at the north.
	Matawan formation.......	Matawan formation, 30 feet thick.	Matawan formation; 10 feet thick at the south; 50 feet thick at the north.

The formations listed differ greatly in thickness from north to south. In general the Eocene strata are lacking at the north and thicken to the south, whereas the Cretaceous strata are well represented in New Jersey but become thin or disappear in Maryland or before reaching that State. Of the New Jersey formations the Shark



SKETCH M

River and Manasquan formations were called by the older New Jersey geologists the "Upper marl bed," the Hornerstown marl was called the "Middle marl bed," the Navesink marl was called the "Lower marl bed," and the Matawan formation was called the "Clay marl bed."

In the writer's opinion the term "marl" should be restricted to earthy deposits containing an appreciable amount of lime. Under this definition most of the greensand deposits of New Jersey and neighboring States should not be called marls, but they have been so generally thus designated in geologic reports and popular speech that it will be difficult to change the usage.

The sketch map (Pl. II) shows on a small scale the distribution of these formations in the three States mentioned and the location of places where samples were taken for analysis.

THE GREENSAND BEDS.

NEW JERSEY.

EXPOSURES OF THE BEDS.

The greensand beds of New Jersey have been described in some detail by previous writers.[1] Only brief notes on the thickness and other features of the sands will be quoted here. These notes will be followed by a list of the localities visited by Mr. Phalen, a statement of the thickness of the greensands sampled by him, and the names of the owners of the land from which the samples were taken. The following data are abstracted from the report by G. H. Cook:[2]

At Highlands, Monmouth County, on the shore of Sandy Hook Bay, the greensand is 25 feet thick and is overlain by 14 feet of clay. On Hop Brook, Atlantic Township, the greensand is 16 feet or more thick and is overlain by 21 feet of clay and low-grade greensand. At a locality about 1¼ miles north of Freehold there is a deposit of greensand 21½ feet thick underlying 7 feet of clay. On McCleas Creek 20 feet of greensand has been dug on the P. J. McCleas place.[3] W. V. Conover dug 21 feet of greensand on the north shore of Navesink River, opposite Redbank. William Smith dug 20 feet of greensand in Nut Swamp, and Azariah Conover dug 25 feet of greensand at Middletown. Pits had been opened along the north slope of the Mount Pleasant Hills from a point above Middletown nearly to Marlboro. Near Holmdel P. R. Smock dug 16 feet of greensand, and on the Schank place, on the north side of Hop Brook, the greensand is 21 feet thick, including, as is common in this area, a 14-inch layer of shells near the middle. At Marlboro Uriah Smock dug 17 feet of greensand. Between Freehold and Englishtown J. C. Thompson dug 15 feet of greensand, and on Manalapan Creek at Black Mills the sand is 20 feet thick. At Cream Ridge 12 feet of greensand has been exposed.

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[1] Rogers, H. D., Description of the geology of the State of New Jersey, 1840. Cook, G. H., Geology of New Jersey, 1868. Clark, W. B., A preliminary report on the Cretaceous and Tertiary formations of New Jersey: New Jersey Geol. Survey Ann. Rept. for 1892, pp. 169–239, 1893. See also Atlas of New Jersey, New Jersey Geol. Survey; and New Jersey Agr. Exper. Sta. Bull. 61, 1916.

[2] Op. cit., pp. 263–276.

[3] The names here given are those of the owners of the land in 1868, when Cook's report was published.

In Burlington County, on Rancocas Creek, three-fourths of a mile northwest of Jacobstown, Mr. Rogers is said to have found 27 feet of greensand, and on the D. G. Lippincott place, half a mile below Mount Holly, 7 to 20 feet of greensand has been found. In Camden County, on Cooper Creek, on the Bridge Kay place, 2 miles from Haddonfield, the greensand is 10 to 15 feet thick. These localities are all on the "lower marl bed" or Navesink marl.

In Monmouth County the "middle marl bed" or Hornerstown marl (or greensand) is 8 to 10 feet thick between Long Branch and Eatontown; 18 feet thick on the Peter Casler place on Town Neck; and 11 feet thick near Eatontown, on the G. A. Corlies place. At Tinton Falls P. Hendrickson dug 10 feet into greensand, and half a mile south of Colts Neck the greensand is 12 to 13 feet thick. About a mile southwest of Blue Ball the greensand is 10 to 14 feet thick, and at Hornerstown it is 11 feet thick.

In Ocean County the greensand is 10 feet thick on Lahway Creek, near Prospertown, and 14 feet thick at New Egypt.

In Burlington County the greensand is 14 to 15 feet thick at Springfield and 22 feet thick at Pemberton. The whole bed is exposed between Vincentown and Eayrstown. It is 15 to 16 feet thick along Sharps Run, west of Medford, and 13 feet thick at Marlton.

In Camden County the greensand is 6 to 13 feet thick at White Horse; 30 feet thick at Laurel Mills, on Big Timber Creek; and 18 to 20 feet thick at Blackwood.

In Gloucester County the greensand is 13 feet thick on Mantua Creek, at Hurffville; 12 feet thick southeast of Barnsboro; and 12 to 20 feet thick on Raccoon Creek.

In Salem County the greensand is 15 feet thick on Nihomus Run; 18 feet thick along Mannington Creek; and 25 feet or more thick on the William Barber place, on Mannington Creek.

The upper bed of greensand is described in Cook's report as consisting of two beds—"green marl" below, 17 feet thick, and a "blue marl" above, 11 feet thick, separated by 9 feet of "ash marl."

In Monmouth County the greensand is 16 feet thick, along Poplar Brook; 18 feet thick on the H. Hurley place on Shark River; 10 to

12 feet thick at Farmingdale, along the Mingumhone; 13 to 15 feet thick at many places along the Manasquan; and 15 feet thick on the Timber Swamp, where dug by the Squankum Marl Co.

In Burlington County the greensand is 12 feet thick at Poke Hill.

In addition to these localities Cook mentions many pits and localities where the greensand has been dug, without giving the thickness found.

SOURCES OF THE SAMPLES.

The locations from which Mr. Phalen obtained samples, the present owners of the land, the observable sections of the beds, and the character of the samples are as follows:

Sample 1 was obtained from the land of Daniel Mahoney, half a mile northeast of Farmingdale, Monmouth County. The section shows 2 to 3 feet of greensand, reported to be 10 feet thick, overlain by 7 feet of black clay, and the clay overlain by 8 to 10 feet of gravel and clay.

Sample 2 was taken on the Mark Kilmartin place, 5 miles northeast of Freehold, Monmouth County, the sample including 15 feet of greensand. The greensand bed in this locality is overlain by 5 feet of clay and gravel.

Sample 3 was taken from the John Van Kirk place, Marlboro, Monmouth County. The 10 feet of greensand sampled is overlain by 3 to 5 feet of gravel. This greensand contains shells.

Sample 4 was taken on the Henry Butterworth place, between Pemberton and Vincentown, Burlington County, 5 feet of greensand being sampled. The bed at this place is overlain by 10 to 15 feet of clay and gravel.

Sample 5 was taken from a heap of greensand previously dug on the Ben Brown place, near Vincentown, Burlington County.

Sample 6 was taken at the same place as No. 5, but the greensand, 5 or 6 feet thick, was sampled in the bed.

Sample 7 was taken from a recently dug pile on the Ivens Horner place, 1½ miles northeast of Pemberton, Burlington County.

Sample 8 was cut in the bed at the place from which sample 7 was obtained, where the greensand is 12 to 14 feet thick and the overburden 8 to 10 feet thick.

Sample 9 is an average sample from 10 feet of greensand, overlain by 2 feet of clay and gravel, on the William Hoffman place, north of Birmingham, Burlington County.

Sample 10 was cut on the Henry Edwards place, 2 miles southwest of Mullica Hill, Gloucester County. The greensand at this locality is 5 feet or more thick and is overlain by 15 to 20 feet of clay and gravel.

Sample 11 was cut from 10 feet of greensand, overlain by 8 to 10 feet of clay and gravel, on the William Wenzell place, just west of Sewell Village, Gloucester County.

Sample 12 was cut from an old marl pit southwest of Laurel Springs, Camden County, where the greensand showed a thickness of 10 to 12 feet, overlain by 20 feet of overburden.

DELAWARE.

As the samples taken in Delaware came from a relatively small area in New Castle County, a sketch map (fig. 1) is presented to show more in detail the locations of the several deposits from which samples were taken.

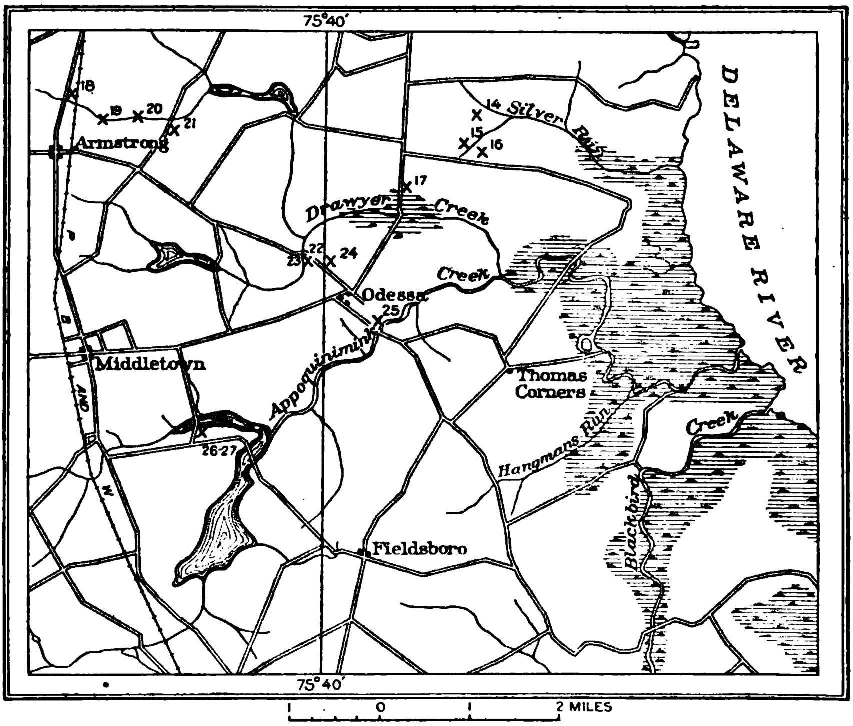

FIGURE 1.—Sketch map of area adjacent to Middletown, Del. ×, Locality from which greensand samples were obtained.

Sample 13 was taken by Mr. Phalen from an old greensand stock heap on the Howard Crossland place, on the Chesapeake & Delaware Canal, west of Delaware City.

Sample 14 was taken near the head of Silver Run from a 5-foot cut in the side of an old pit on the C. E. Pool place, formerly the Karsner place. This pit is about 20 feet deep to the water now standing in it. The greensand at this point was reported by Booth[1] to have a thickness of 25 feet. The pit is said to have been last worked about 35 years ago. Its banks have fallen in and are overgrown with trees. The cut was made near the top of the greensand, where the bank was steepest and the talus thinnest. The upper 10 or 12 inches of the section sampled (sample 14B) is light green and resembles clay in grain and physical properties. The analysis shows it to contain 6.85 per cent of potash. The remainder of the sample represents dark-green sand with which are mixed many hard green and dark-red indurated slabs, averaging about one-half inch thick. This sample comes from the Rancocas formation. Booth[2] reports 8.50 per cent potash as the average of this pit.

Booth[3] reports greensand on the S. Townsend place 23 feet thick, on the J. Vandegrift place, and on the Glazier place. These pits could not be located, but in searching for them greensand was noted at location 15, possibly not in place, for it appeared only as an irregular film over the bottoms of a branch of Silver Run. Sample 15 was taken at this place.

Sample 16 was taken not far from the place where sample 15 was obtained. Greensand at this place had been brought to the surface from a woodchuck burrow. The thickness and character of the sand is not known at either location 15 or 16.

There are a number of pits on both sides of the old State road north and south of the crossing of Drawyer Creek, and greensand is well exposed in a cut on the road north of the bridge. It appears to form the surface of the ground south of the bridge as far as the Drawyer Cemetery. Booth[2] reports the greensand as mined north of the creek on Mrs. L. Sims's farm east of the road and on the J. Rogers place west of the road. The freshest exposure seen was in the cut on the road at location 17, about 30 feet above sea level at the bridge. The greensand at this point appears to be confined to a narrow strip, for exposures in the cut on the west side of the road and in the hill above the point mentioned on the east side of the road show no greensand, but only yellow and red sand and the gravel of the Talbot formation of Quaternary age. Sample 17, taken at this place, represents a 6-foot cut.

The south prong of the north fork of Drawyer Creek is cut in the Monmouth formation, from a point west of the railroad, for a mile or more downstream. The greensand is exposed only at the creek level or for 1 or 2 feet above it. Samples 18 to 21 were taken at points along that branch.

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[1] Booth, J. C., Memoir of the geological survey of the State of Delaware, p. 55, Dover, 1841.

[2] Idem, p. 56.

[3] Idem, pp. 54, 55.

Sample 18 was taken just east of the State road, between the road and the railroad track. It consisted of material from a 2-foot cut, 1 foot being taken above the water level of the stream and 1 foot taken below the water level.

Sample 19 was obtained from a woodchuck mound a few feet above the level of the stream bottom, a short distance east of the railroad.

Sample 20 was cut in the shallow bank of the stream, at and below water level.

Sample 21 was taken about 100 yards south of the bridge at this point, where about 10 feet of coarse yellow sand is exposed. This sand contains layers and patches of black sand, suggestive of oxidized glauconite. The sample analyzed consisted of portions of these black bands. Similar dark micaceous sand shows in the drains for some distance south of the bridge. Where sampled, the black material made up from 10 to 20 per cent of the whole.

Sample 22 was taken from a small exposure of high-grade greensand south of Drawyer Creek, at the point where the road from Odessa turns southeast. Only 2 feet of the greensand is exposed. It is overlain by a small thickness of yellow sand and gravel. This sample represents a 2-foot cut made at the side of the road.

Sample 23 was taken at the same point as sample 22, but it represents water-laid material taken from the bed of a little drain that was cut in the greensand at this point. The sample was taken in order to see what effect, if any, was produced on the material by erosion and transportation downstream, which possibly involved separation of the greensand from any associated clay and other matter that might have been carried away by the flowing water in which the sands were deposited. It was thought that this sample might show a concentration of the greensand and a somewhat higher percentage of potash. The analyses, however, show that the original deposit was so nearly pure glauconite that little or no concentration could take place, for they differ only by 0.02 per cent of potash and both show the highest percentage of any of the samples obtained, with the exception of the green clay that forms sample 14B.

About one-fourth of a mile south of the bridge on the east side of the road on which sample 22 was obtained a greater thickness of greensand is exposed, and the material that is revealed appears to belong stratigraphically above that sampled at location 22. Sample 24, which was taken at this place, represents a 6-foot cut. The greensand here appears to be less uniform than that at locality 22 and to be much harder; in part it is indurated with iron.

The Rancocas formation, from which samples 22 to 24 were taken, crops out along both forks of Appoquinimink Creek.

Sample 25 was cut in the bluff behind the wharf house at Odessa, just east of the old State road. The bank contains 15 to 18 feet of a red sand that is streaked with gray and locally hardened by iron. This sand has a faint greenish tinge, due to the presence of a small amount of glauconite.

Samples 26 and 27 represent two cuts on the north fork of Appoquinimink Creek, opposite the Reese mill, on the south side of the fork and beneath the floor of the old sand and gravel pit.

Sample 26 was taken from a 3-foot cut at the top of the bluff at this locality, and sample 27 from a 2-foot cut immediately below the 3-foot cut but made somewhat deeper into the face of the bluff. The upper cut contains many hard slabs, indurated with iron, which were absent in the lower cut and which presumably represent the results of incipient weathering.

MARYLAND.

In Maryland the greensand was sampled at only two points, which were selected after inquiry of the geologists who had worked over the area. The greensand at these points and that at Fort Washington, which was not sampled, was thought to be the most promising and to best fulfill the conditions of nearness to routes of transportation.

Two samples, 28 and 29, were cut in the cliffs on the north side of Severn River, in Anne Arundel County, about half a mile and 1 mile above the Annapolis Short Line bridge. The section shows from 30 to 70 feet of sand, most of which is a deep yellow brown at the surface. Many streaks of indurated sand are present. Toward the bottom the effects of weathering are less marked, and even at the exposed surface the sand has a greenish tinge. When examined with a hand lens, it has the appearance of pepper and salt. Two cuts, each 5 feet long, were made a fraction of a mile apart. The thickness of the greensand here is great, but it is uncertain to what extent it may be weathered, as the grain appears to be rather open. The sand at the bottom of the cliff runs low in potash, but the greensand could be readily separated from the coarse sand.

Samples 30 to 34 were taken in a long cut on the Chesapeake Beach Railway, in Prince Georges County, about halfway between Upper Marlboro station and Pennsylvania Junction. The face of the cut has a depth of about 30 feet, of which the upper 15 feet consists of sand and thin layers of gravel, deep reddish yellow at the top and reddish green at the bottom. This material is underlain by 15 feet or more of greensand. Sample 30 represents a 5-foot cut at the top of the greensand bed in the west end of the cut. This material is very fine grained and cuts like clay. Samples 31 and 32 are from a 2-foot cut made just below the last. Sample 31 was taken directly in the surface of the railroad cut, where the material was obviously weathered; then a trench was dug 2 feet or more in depth to a point where the greensand had lost all appearance of weathering, and at the back of this trench sample 32 was taken. Samples 33 and 34 were cut at the east end of the cliff, sample 33 representing a 6-foot cut whose base was 4 feet above the track, and sample 34 a 3-foot cut just under the 6-foot cut. In both these samples the material cut like wet clay but broke like a sand. Sample 33 carried some streaks of ocher-yellow material, from which sample 34 was free, and sample 34 carried a considerable quantity of shell fragments, which doubtless gives it a high percentage of lime.

Traces of greensand occur in the long cut on the Pennsylvania Railroad south of Marlboro station. At one point, where sample 35 was taken, the cut exposes 10 feet or more of dark-drab and light-drab clay and brown sand, containing spots of bright greensand and locally flecks of cobalt-blue material, which was not studied but is supposed to be vivianite, or hydrous iron phosphate.

Two cuts were made on the bank beside the road, just north of the bridge at Marlboro. The section shows 10 feet of reddish-brown sand (Nanjemoy formation), 32 feet of coarse-grained olive-green sand, 2 feet of indurated greensand with shells, and 5 feet of unconsolidated greensand with shells. Sample 36 represents a 10-foot cut starting at the top of the 32-foot bed of greensand. Sample 37 represents a 5-foot cut starting 15 feet below the other. All of the section except the upper 10 feet are in the Paspotansa member of the Aquia formation.

Just west of this road cut are old openings that appear to have been extensive greensand pits.

Samples 38 and 39 represent the material from two 3-foot cuts, one above the other, made in the perpendicular bank of a small gully about a quarter of a mile west of the road cuts just described. This sand appeared to be less weathered at the surface than that at the road. The upper cut (sample 38) differed from the lower in showing traces of weathered pyrite, whereas the lower section showed much limonite.

VIRGINIA.

Three samples were taken in Virginia, all at the same locality in Henderson Bluff on Potomac River, 1 mile below the mouth of Aquia Creek, and about 6 miles east of Brooke station, on the Richmond, Fredericksburg & Potomac Railroad. A plant for drying and shipping the greensand has been put up at this point by B. L. Henderson, of Baltimore. This is the type locality of the Aquia formation. The section given by the Maryland Geological Survey is as follows:[1]

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[1] Maryland Geol. Survey, Eocene, p. 69, 1901.

Section on Potomac River below the mouth of Aquia Creek.

	Feet.
Pleistocene:	
Fine sand, light yellow, with white clay at base	26
Eocene:	
Aquia formation:	
Paspotansa member:	
Fine sand, light green; contains a few glauconite grains (zone 10)	10
Thick-bedded sandy and glauconite limestone (zone 9)	30
Fine sand, green or gray (zone 8)	30
Piscataway member:	
Dark greensand, containing broken shells (zone 7)	7
Dark greensand, containing whole shells (zone 6)	1
Light greensand, indurated (zone 5)	2
Greensand marl (zone 4)	8
Dark greensand, indurated (zone 3)	2
Greensand marl (zone 2)	16
	132

Where the samples were cut, zone 2 has a greater thickness than that given in the section—at least 20 feet where samples 41 and 42 were cut and 22 feet where sample 40 was cut.

Sample 40 was taken from a 5-foot cut in the top of the 8-foot layer of greensand (zone 4) immediately back of the drying plant. Samples 41 and 42 were cut a short distance west of the plant. Sample 41 represents a 5-foot cut at the top of zone 2; sample 42 a 3-foot cut in the same bed, just above the shore. All the cuts include sands containing large quantities of shell fragments, so that the percentage of lime is probably from 50 to 75 per cent, necessarily greatly reducing the percentage of potash in the samples. The upper part of the section includes sands that show small percentages of glauconite. When crushed in the hand these sands suggest salt that has been slightly sprinkled with pepper.

NORTH CAROLINA.

The greensand of North Carolina was sampled at only one locality—a bluff 1 mile above Edwards Bridge, on the north side of Contentnea Creek, about 6 miles above Grifton, a station on the Atlantic Coast Line Railroad a few miles northeast of Kingston. The greensand at this point was said by L. W. Stephenson to appear to be much greener than any other that he had seen in the State. It is overlain by 6 to 8 feet of clay and yellow sand and gravel. The richer portion of the sand is 4 feet thick. Sample 43, taken at this locality, is a light-greenish sand, containing considerable quartz. Below the layer sampled lies 8 feet of dark-gray sand, which here and there contains small stringers of greensand a few inches long and less than an inch thick. Sample 44 represents a 7-foot cut in this bed.

The greensand is reported to have been struck in ditches some distance north and east of this bluff. About a quarter of a mile above Edwards Bridge, nearly 5 feet of the lower bed is exposed in a bluff on the north bank. The greensand is overlain directly by the surface sand and gravel. The lower bed at this point is represented in sample 45.

TENNESSEE.

Troost,[1] the first State geologist of Tennessee, gave in his seventh annual report analyses of greensands from McNairy County, Tenn., showing from 10.10 to 11.30 per cent of potash. A preliminary study of this subject by the writer led to the belief that these analyses represented results not from samples of the bed as a whole but of selected grains of greensand, as appears to have been the custom at that period. Further, the analytical method then in use for the determination of the content of potash appears to have been faulty, and to have yielded too high a percentage of potash, even for the glauconite grains.

In Nashville the writer examined the samples of greensand (?) collected by Mr. Wade, of the State Geological Survey, in McNairy and adjacent counties, in a detailed study recently made of that area. None of the material so collected revealed any greensand under the hand lens. The writer then spent two days in examining railroad and road cuts in southeastern McNairy County without finding any trace of greensand. Most of the "sand" of the region seen in wells and the deeper railroad cuts is a dark, sandy shale, very dark when wet. Sample 46 came from a well nearly 5 miles northeast of Selmer.

Sample 47 represents the weathered surface material exposed in a road cut. All the soil of the region has a faint greenish-yellow tinge. Neither of the samples reveals any glauconite under the lens, though each contains considerable mica and possibly other potash-bearing material. The samples collected by Mr. Wade have been examined by Mr. Bowers, of the State Survey, who reports less than 3 per cent of potash.

ARKANSAS.

The only greensands in Arkansas that promised to be of value were represented by small specimens collected at Washington, Hempstead County, by L. W. Stephenson, which on analysis yielded 4.90

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[1] Troost, Gerard, Seventh report of the geological survey of Tennessee, p. 80, 1844.

per cent potash. A suite of samples was therefore collected in that area, with the aid of Mr. William Taylor, of the Bureau of Soils, who was at that time making a survey of the soils of the county. The best exposure of sand was found in a road cut one-quarter of a mile or less east of the station at Washington. The section shows, from the top downward, 10 feet of greenish-gray sand, with bands of iron-stained sand; 7 feet of greenish-gray sand, of which sample 48 represents the upper 3 feet and sample 49 the lower 4 feet, which is much greener and richer than the top of the bed; 6 inches to 1 foot of calcareous hard greenish-gray sand; 4 feet of dark sand that has a pepper-and-salt appearance, from which sample 50 was obtained; 3 feet of dark sand containing much dark calcareous matter. Just east of Holz's store, on the J. R. Jones road, three sections were cut. Sample 51 represents 1 foot at the top of the section, including the oxidized red sand at the top of the road cut. Sample 52 represents a 2-foot cut immediately below the 1-foot cut, showing the same materials, only slightly weathered. Sample 53 is from a 3-foot cut, starting 1 foot below the bottom of the cut made for sample 52.

Samples 54 to 56 were taken in a road cut on the J. K. Jones road, about 3 miles from Washington. Sample 54 represents a 4-foot cut in the upper part of the section, sample 55 a 2-foot cut a few feet lower, and sample 56 a 3-foot cut at a horizon still lower.

The work of Mr. Taylor has shown an area of several square miles of greensand around Washington. The results of the sampling show that much of the greensand is low in potash, though sample 50 shows that some of the bed is, at least locally, fairly good.

ANALYSES OF GREENSANDS.

Results of analyses of the samples collected are given in the following table:

Analyses of greensands.

[W. B. Hicks and R. K. Bailey, analysts.]

No.	Locality.	Potassium.	Potash.	Analyst.
1	Farmingdale, N. J	2.94	3.54	Hicks.
2	Freehold, N. J	3.69	4.45	Do.
3	Marlboro, N. J	3.69	4.45	Do.
4	.....do	3.56	4.28	Do.
5	Vincentown, N. J	3.10	3.74	Do.
6	.....do	3.50	4.22	Do.
7	Pemberton, N. J	3.50	4.22	Do.
8	.....do	3.94	4.74	Do.
9	Birmingham, N. J	5.85	7.07	Do.
10	Mullica Hill, N. J	5.94	7.15	Do.
11	Sewell, N. J	5.89	7.09	Do.
12	Laurel Springs, N. J	5.31	6.40	Do.
13	3 miles west of Delaware City, Del	2.80	3.36	Do.
14	Silver Run, Del	5.10	6.15	Bailey.
14B	.....do	5.69	6.85	Do.
15	.....do	2.55	3.07	Do.

Analyses of greensands—Continued.

No.	Locality.	Potassium.	Potash.	Analyst.
16	Silver Run, Del	3.58	4.32	Bailey.
17	Drawyer Creek, Del	5.18	6.25	Do.
18	South prong of north fork of Drawyer Creek, Del	2.10	2.53	Do.
19	....do	3.17	3.82	Do.
20	....do	1.62	1.95	Do.
21	....do	2.02	2.42	Do.
22	Drawyer Creek north of Odessa, Del	5.53	6.67	Do.
23	....do	5.52	6.65	Do.
24	....do	4.43	5.34	Do.
25	Odessa, Del	1.32	1.59	Do.
26	Appoquinimink Creek, Del	4.72	5.68	Do.
27	....do	4.43	5.33	Do.
28	Severn River, Md	2.52	3.04	Hicks.
29	....do	2.42	2.92	Do.
30	East of Upper Marlboro, Md	2.17	2.62	Do.
31	....do	2.02	2.43	Do.
32	....do	1.34	1.62	Do.
33	....do	2.06	2.48	Do.
34	....do	2.42	2.92	Do.
35	Marlboro, Md	....	....	
36	....do	3.69	4.45	Do.
37	....do	3.15	3.79	Do.
38	....do	2.76	3.32	Do.
39	....do	3.21	3.86	Do.
40	Aquia Creek, Va	1.73	2.08	Do.
41	....do	1.95	2.34	Do.
42	....do	1.20	1.44	Do.
43	Contentnea Creek, N. C	2.46	2.96	Bailey.
44	....do	1.14	1.37	Do.
45	....do	1.12	1.35	Do.
46	East of Selmer, Tenn	1.95	2.35	Do.
47	....do	1.69	2.18	Do.
48	Washington, Ark	2.67	3.22	Hicks.
49	....do	3.68	4.43	Hicks and Bailey.
50	....do	3.16	3.80	Hicks.
51	East of Washington, Ark	2.42	2.92	Do.
52	....do	3.63	4.37	Hicks and Bailey.
53	....do	3.57	4.30	Hicks.
54	....do	3.76	4.53	Hicks and Bailey.
55	....do	3.09	3.72	Bailey.
56	....do	2.32	2.80	Do.

Samples 1-13, inclusive, were collected by W. C. Phalen. Samples 14-56, inclusive, were collected by G. H. Ashley.

CONCLUSIONS.

From the above descriptions and analyses it is evident that, so far as present information goes, the best greensands are in New Jersey and Delaware; that the deposits in places have a maximum thickness of 20 or 30 feet, though as a rule it is less; that these deposits have a horizontal extent of many miles; that the quantity varies both in different parts of the section of the bed at the same place and from place to place; that in the main these beds outcrop at the surface and have a cover as a rule not more than their own thickness; that locally these deposits carry more than 7 per cent of potash, and that over large areas they carry from 5 to 7 per cent of potash; and that many of the deposits are close to transportation and so situated that they could be mined by dredge or steam shovel readily and cheaply.

The deposits examined south of Delaware are of lower grade. It is probable, however, that all of those examined have a sufficient extent for commercial use, if a cheap method of obtaining the potash can be found.

In view of the relative rapidity with which the potash becomes "available" or "soluble" when the greensand is used as a fertilizer in the ground, the question naturally arises as to whether the action of carbon dioxide, humic acid, or some of the other acids of the earth might not prove a possible solvent of the potash, for carbon dioxide could be readily obtained from limekilns in adjoining areas at little or no cost, and the product, if the process succeeded, would be in the form of potassium carbonate.

Experiments were made in dissolving the potash of the greensand in a solution of carbon dioxide. An automatic agitator was used and the tests lasted several hours. The solution contained such a small amount of potash, however, as to indicate that the process was not commercially feasible. Similar experiments, with like results, were carried on with sulphur dioxide, which could be obtained as a by-product from the smelters, and dilute hydrochloric acid also failed to give results of value.

As the subject of the processes of possible utilization of the greensands in the production of commercial potash is not within the province of this paper, no detailed study of the subject was made, and the experiments referred to were merely incidental to the analytical work, so that they may not be conclusive. The results obtained, however, do not lend hope to the successful use of such methods.

The concentration of the glauconite of the greensand by electric magnets should be entirely feasible, by employing possibly such methods as are to-day in use in concentrating low-grade ferruginous zinc ores. The chapters on potash salts in Mineral Resources of the United States for 1913 to 1915 contain descriptions of methods proposed for the commercial extraction of potash from many of the minerals and rocks that contain it. The advantage of greensand over feldspars lies in its abundance and possible low first cost, exclusive of freight.

METHODS OF ANALYSIS OF GREENSAND.

By W. B. Hicks and R. K. Bailey.

INTRODUCTION.

Owing to the fact that wide variation in the potash content of greensand marls is shown by several reports on the subject, it seems desirable to bring together here a brief summary of the methods of analysis that have previously been used, together with the method used in the present investigation. This comparison will explain the lack of concordance and will bring out more or less clearly the results which are not to be trusted on account of defective methods. Furthermore, the procedure which we have used is a departure from the usual methods of determining potash in silicate rocks and therefore requires description.

EARLIER METHODS.

ROGERS'S METHOD.

In his report on the greensand marls of New Jersey, Rogers[1] presented the results of a great many analyses of purified glauconite grains. By his method the sample was digested in a flask with rather strong hydrochloric acid for three days, or was boiled vigorously for five or six hours. The solution was filtered, and the undissolved portion was weighed and reported as silica. The iron and alumina were precipitated from the filtrate by ammonia and were separated from each other by caustic soda. The ammonium salts were removed by evaporating the solution to dryness and igniting the residue. The residue after ignition, which was assumed to consist of chlorides of calcium, magnesium, and potassium, was weighed, dissolved in water, diluted to definite volume, and divided in half. In one portion the calcium was precipitated as oxalate and determined as oxide, and the magnesium was determined as pyrophosphate. Their equivalents as chlorides were subtracted from the weight of the combined chlorides and the remainder reported as potassium chloride. As a check determination of the potassium, the second portion of the solution was evaporated to dryness, the dry chlorides were extracted with alcohol to remove the calcium and magnesium, and the residue was weighed and reported as potassium chloride. It is stated that when necessary the salt was converted into potassium chloroplatinate and weighed, but no information is given as to which, if any, of the determinations were actually made according to the chloroplatinate method.

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[1] Rogers, H. D., Description of the geology of the State of New Jersey, pp. 186–216, 1840.

A great many analyses of carefully picked and purified greensand grains gave on an average 11.5 per cent of potash (K_2O), 0.5 per cent of lime (CaO), and a trace of magnesia (MgO). Soda is not reported. The high value for potash is evidently due to the defective methods of analysis. It seems certain that the soda is reported as potash and probably also a large portion of the magnesia and some of the silica, except in those results obtained by the chloroplatinate method. As there is no way of differentiating between the good and bad, all the results for potash in this report should be considered unreliable.

KOCH AND SMOCK'S METHOD.

In Cook's report[1] the analyses represent the material as it came from the pit and were made by Julius Koch and John C. Smock. Although the methods are very vaguely described, it appears that Koch decomposed the marl by digestion with hydrochloric acid, precipitated the iron and alumina by ammonia, removed the calcium by precipitation as calcium oxalate, separated the magnesium as oxide by means of a solution of barium hydrate and acetate, removed the excess of barium by sulphuric acid, evaporated the filtrate to dryness, and finally ignited and weighed the residual potassium sulphate. Smock decomposed the marl by digestion with hydrochloric acid, precipitated the iron and alumina by ammonia, and determined the potash as chloroplatinate after removing the ammonium salts and probably also the calcium and magnesium.

The digestion with hydrochloric acid would probably decompose the glauconite completely and take into solution the potash contained in it, but would not attack materially the feldspar and other potash minerals likely to be present. This method would tend to give low results for total potash when potash minerals other than glauconite were present. Unless a double precipitation was made, the iron precipitate would hold back some of the potash, causing low results in both methods. Koch weighed sodium sulphate and probably some magnesium sulphate and silica with the potassium sulphate, which no doubt caused high results. On the whole, however, the errors tend to balance each other. Smock, who used the chloroplatinate method, should have obtained more trustworthy results.

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[1] Cook, G. H., Geology of New Jersey, pp. 414–470, 1868.

METHODS USED BY THE UNITED STATES GEOLOGICAL SURVEY.

PROCEDURE.

For several years a modified chloroplatinate method for the determination of potash has been used by the Geological Survey, more especially in those determinations relating to the search for potash.[1] This procedure is applicable in the presence of sulphates, the alkaline-earth metals, and small quantities of aluminum, iron, silica, and other substances. A further modification of this method here described is applicable in the presence of large quantities of iron and aluminum and has been adapted especially for the determination of potash in glauconite. It is much shorter than any other known method, and the results obtained by its use are in close agreement with those obtained by the J. Lawrence Smith method.[2] It was adopted after many preliminary experiments.

The mineral is decomposed by hydrofluoric and sulphuric acids, the excess of acids expelled by gentle ignition, and the residue dissolved in dilute hydrochloric acid. The solution thus obtained is evaporated to dryness in the presence of a slight excess of chloroplatinic acid. The residue is washed with 95 per cent alcohol containing 20 cubic centimeters of concentrated hydrochloric acid in a liter in order to remove the excess of chloroplatinic acid and soluble chloroplatinates. It is then washed through the filter with hot water, the potassium chloroplatinate reduced to metallic platinum by means of magnesium, and the platinum weighed. From the weight of the platinum the weight of potash is calculated.

Weigh out a half-gram sample of the mineral which has been ground to pass a 200-mesh sieve, place in a small platinum dish or a large platinum crucible, moisten with a few drops of water, and add about 10 cubic centimeters of hydrofluoric acid and the equivalent of about half a cubic centimeter of concentrated sulphuric acid. Hold the dish with the tongs and heat it and its contents cautiously over the free flame until the mineral is broken up and apparently completely decomposed, which requires only a very few minutes.

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[1] Hicks, W. B., Jour. Ind. Eng. Chemistry, vol. 5, p. 650, 1913.

[2] Am. Jour. Sci., 3d ser., vol. 1, p. 269, 1871; Am. Chemist, vol. 1, 1871; Annalen der Chemie und Pharmacie, vol. 159, p. 82, 1872. Hillebrand, W. F., U. S. Geol. Survey Bull. 422, p. 171, 1910 (reprinted, 1916).

The dark color due to organic matter should be disregarded. Evaporate the solution on the steam bath to complete dryness, and during this operation agitate the solution occasionally by giving the dish a gyratory motion with the tongs. This treatment is nearly always sufficient to decompose the mineral, but if decomposition seems incomplete add more hydrofluoric acid and evaporate a second time, agitating the mixture frequently. Heat the dish and its contents on a radiator[1] to expel the excess of hydrofluoric and sulphuric acids. Finally ignite gently to make sure of the complete removal of ammonium salts and to destroy organic matter. This operation will also expel much of the sulphuric acid combined with the iron and aluminum, but care should be taken not to heat high enough to render the iron and aluminum insoluble in hydrochloric acid. Cover the residue with dilute hydrochloric acid, which must be free from ammonium salts, and digest on the steam bath until solution is complete, adding more water and acid if necessary. Flakes of organic matter and a few grains of sand which remain undissolved may be neglected, but large amounts of undissolved calcium sulphate should be brought into solution.

The solution of the completely decomposed mineral is now filtered into a small Jena glass or porcelain evaporating dish, chloroplatinic acid slightly in excess of that necessary to combine with all the potassium present is added, and the solution evaporated on the steam bath until nearly all the hydrochloric acid is removed and the mass solidifies on cooling. Cover the residue with an alcohol-acid solution prepared by adding 20 cubic centimeters of concentrated hydrochloric acid to 1 liter of 95 per cent alcohol. Chloroplatinic acid and its soluble salts are likely to be occluded in the ferric sulphate and basic salts formed on evaporation, making their complete removal troublesome. The acid in the alcohol wash liquid tends to correct this difficulty by destroying the basic salts and changing a portion of the ferric sulphate into chloride, which is readily soluble in alcohol. If the residue is amorphous stir up the mixture gently with a glass rod made into a pestle and allow it to stand until it becomes crystalline, then grind up the residue thoroughly with the pestle and allow it to stand a half hour, or until it becomes quite crystalline. Decant the solution through a filter paper. Grind the residue thoroughly with the pestle, add 10 cubic centimeters of the alcohol-acid wash solution, stir thoroughly, allow the suspension to settle, and decant the solution through the paper. Continue the washing by decantation, using small portions of the alcohol-acid solution and thoroughly stirring up the residue after each treatment, until the excess of chloroplatinic acid has been completely removed, but be careful to keep the quantity of wash liquid around 75 cubic centimeters.

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[1] Hillebrand, W. F., U. S. Geol. Survey Bull. 422, p. 31, 1910 (reprinted, 1916). A large porcelain crucible serves well as a radiator for this purpose.

Dissolve the residue, which consists of potassium chloroplatinate mixed with salts of iron, aluminum, calcium, sodium, and other metals, in hot water, and wash the solution through the filter into a convenient-sized beaker. Acidify with hydrochloric acid, heat almost to boiling, and reduce the chloroplatinate to platinum by stirring the solution with a wad of magnesium ribbon held on the end of a glass rod, taking care to keep the solution slightly acid. About 1 cubic centimeter of concentrated hydrochloric acid and 0.5 gram magnesium should be added for each 0.2 gram of potassium present. After the complete reduction of the platinum and the complete solution of the magnesium allow the mixture to stand on the hot plate for an hour or so. The platinum will coagulate on the bottom of the beaker, and the solution will become colorless and limpid like water. To make sure of complete reduction add more magnesium, when, if reduction is incomplete, the solution will darken. Finally add strong hydrochloric acid, boil the solution, filter through paper, and wash thoroughly with hot water. The platinum is then ignited in a small porcelain crucible, cooled in a desiccator, and weighed. The weight of platinum multiplied by 0.4826 gives the weight of potassium as the oxide, K_2O.

PRECAUTIONS TO BE OBSERVED.

Pure glauconite is readily brought into solution by hydrofluoric acid, and the associated minerals are usually decomposed with little difficulty. If care is taken, after the expulsion of the excess of hydrofluoric and sulphuric acids, to insure complete solution in hydrochloric acid, no error should result from this part of the operation. The resulting solution, which contains all the iron and aluminum of the mineral, usually leaves a gummy residue on evaporation with chloroplatinic acid. On treatment with the alcohol-acid wash liquid, the residue often assumes the amorphous or noncrystalline condition. In this event the mixture should be set aside and the mass allowed to become crystalline; otherwise the washing can not be done successfully. The crystalline residue should be ground finely to enable the wash liquid to get at any inclosed soluble chloroplatinates, and special care must be taken to insure complete washing of the residue with a minimum amount of the alcohol-acid wash liquid. Therein lies one of the chief sources of error in the method. If all the soluble chloroplatinates are not removed the results, of course, will be too high and this error may be considerable unless special pains are taken to grind up all the lumps and to wash thoroughly. On the other hand, if too much wash liquid is used the results are likely to be too low, because of the solubility of potassium chloroplatinate in alcohol acidified with hydrochloric acid. This error is not likely to be large, but the wash liquid should be kept around 75 cubic centimeters.

The solution containing the potassium chloroplatinate mixed with iron and other salts, which was obtained by washing the residue through the filter with hot water, should be kept sufficiently acid to prevent the formation of basic iron salts during the subsequent reduction of the platinum; otherwise the precipitate may be contaminated with iron. As a further precaution the solution containing the precipitated platinum should be acidified with strong hydrochloric acid and boiled just before filtering. Of course, the platinum must be completely reduced.

SOLUBILITY OF POTASSIUM CHLOROPLATINATE IN ALCOHOL ACIDIFIED WITH HYDROCHLORIC ACID.

An approximate determination of the solubility of potassium chloroplatinate in alcohol acidified with hydrochloric acid was made in order to determine whether or not such a solution could be used as a wash liquid in potash determinations. The potassium chloroplatinate was prepared by adding a slight excess of chloroplatinic acid to a strong solution of pure potassium chloride. The solution was filtered and the residue was washed with alcohol. After drying the potassium chloroplatinate so obtained was recrystallized from water, dried at 130° C., and preserved for use.

The solubility determinations were made by taking 550 cubic centimeters of the alcohol-acid mixture in a 1-liter glass-stoppered bottle, to which about 4 grams of potassium chloroplatinate were added. The stopper was inserted and sealed with paraffin. The bottle was then placed in a shaking machine and shaken violently end over end for 7 to 14 hours. The undissolved portion was allowed to settle, the solution was filtered, and 500 cubic centimeters of the filtrate were evaporated to dryness on the water bath. The residue was dissolved in hot water, and the platinum reduced to metal with magnesium and finally weighed. The acidity was determined by titrating 10 cubic centimeters of the filtrate with tenth-normal sodium hydroxide solution, using phenolphthalein as indicator. The approximate strength of alcohol was calculated from the quantity of 95 per cent alcohol and concentrated hydrochloric acid used in each mixture. The temperature at which the determinations were made was approximately 25° C. By this procedure the following results for the solubility of potassium chloroplatinate in alcohol acidified with hydrochloric acid were obtained:

Solubility of potassium chloroplatinate in alcohol acidified with hydrochloric acid.

No.	Time of shaking (hours).	Solution (cubic centimeters).	Platinum (gram).	K_2PtCl_6 (gram).	Solubility.		HCl per liter (grams).	Approximate strength of alcohol (per cent by volume).
					Gram per liter.	Solution dissolving 1 gram of K_2PtCl_6 (cubic centimeters).		
1	7	500	0.0078	0.0194	0.0388	25,800	6.82	93
2	14	500	.0081	.0201	.0402	24,880	6.82	93
3	14	500	.0152	.0379	.0758	13,190	13.40	91.5

The first two determinations recorded in the table are duplicates except for the time of shaking. The alcohol-acid mixture was prepared by adding 20 cubic centimeters of concentrated hydrochloric acid to 1 liter of 95 per cent alcohol. The acidity of the solution, which was determined by titration, was 6.82 grams of hydrochloric acid per liter, and the strength of the alcohol was calculated to be approximately 93 per cent. The mean of the two determinations gave for the solubility of potassium chloroplatinate in the solution 0.0395 gram per liter—that is, 1 gram of potassium chloroplatinate was dissolved by 25,340 cubic centimeters of the alcohol-acid mixture. The solubility of potassium chloroplatinate in 80 per cent alcohol, which is usually recommended for washing, is about 1 gram in 26,400 cubic centimeters of alcohol.[1] The solubilities are of the same order and the difference is of no significance in the determination of potash.

The third determination shows that the solubility increases rapidly with the acidity. Therefore care should be taken not to use a wash liquid containing more than 20 cubic centimeters of hydrochloric acid in a liter of 95 per cent alcohol.

COMPARISON OF RESULTS BY DIFFERENT METHODS.

Potash was determined in a number of glauconite samples by the hydrofluoric acid method described by Treadwell,[2] as the procedure is very short. The method was abandoned, however, as the results were soon found to be too low. The values actually obtained are given in the table below for the purpose of comparison. In order to check results and to give experimental proof of the reliability of the new method which has been developed the potash in a number of glauconite samples was determined by the J. Lawrence Smith method and by the new method described on page 53. The results are presented in the table on page 58.

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[1] Precht, H., Zeitschr. anal. Chemie, Jahrg. 18, p. 513, 1879.

[2] Treadwell, F. P., Analytical chemistry, vol. 2, p. 397, New York, John Wiley & Sons, 1909.

Percentage of potash in glauconite determined by different methods.

No.	J. Lawrence Smith method.[a]	New method.	Hydrofluoric acid method.[b]
1	3.62	3.54 3.53	....
2	4.46 4.48	4.30 4.54	....
3	4.48	4.46 4.40	....
8	4.70	4.78 4.74	....
9	7.08	6.98	6.26
10	7.18 7.20	7.00 7.10 7.24 7.16	6.01 ....
11	7.13	7.08 7.06	6.22 ....
12	6.45	6.36 6.38	5.66 ....
40	2.10	2.07	....
41	2.50 [c] 2.56	2.41 2.27 [c] 2.35	....
42	1.45 [c] 1.50	1.52 1.35 [c] 1.35	....
44	[c] 1.31	[c] 1.29	....
X [d]	7.12 6.99	7.04 7.06	6.64 ....

[a] Hillebrand, W. F., The analysis of silicate and carbonate rocks: U. S. Geol. Survey Bull. 422, p. 171, 1910 (reprinted, 1916).

[b] Treadwell, F. P., Analytical chemistry, vol. 2, p. 397, 1909.

[c] Determinations by R. K. Bailey.

[d] Practically pure glauconite grains separated from sample 36 by an electromagnet.

By reference to the table it will be observed that the results by the hydrofluoric acid method are considerably lower than those by the other two methods. In the hydrofluoric acid method the sulphate, iron, aluminum, calcium, and other substances were precipitated and removed in one operation. The precipitate, no doubt, retains considerable potash, which is exceedingly difficult to remove by washing. This explains the low results. The data show that this method is not satisfactory when the precipitate is large, especially if considerable potash is present.

It will be observed also that nearly all the results by the other two methods agree very closely. No. 41 shows the widest variation. In general the results by the new method are a little lower than those by the J. Lawrence Smith method, and the variations among themselves are more pronounced. Although the new method requires care and experience in manipulation and gives little lower and slightly more discordant results than the J. Lawrence Smith method, it is believed to be accurate enough for commercial work, and probably for all purposes except where extreme accuracy is desired. The procedure is much shorter than any other known method for determining potash in silicate rocks, and admits of carrying out several analyses simultaneously.

Practically all the determinations presented in this report have been carried out in duplicate by the new method, and it is believed that the results are very nearly correct, the maximum deviation being about 0.2 per cent.

MANGANESE DEPOSITS OF THE CADDO GAP AND DE QUEEN QUADRANGLES, ARKANSAS.

By Hugh D. Miser.

INTRODUCTION.

The high prices that are being offered for manganese ores have stimulated interest in the little-exploited manganese deposits of west-central Arkansas. These deposits are found at intervals in a belt 4 to 12 miles wide, extending west-southwestward from Pulaski County, at the center of the State, to Polk County, on the west border. Recent exploitation, begun in 1915 and still in progress, is confined almost entirely to the mountainous districts in the northern parts of the

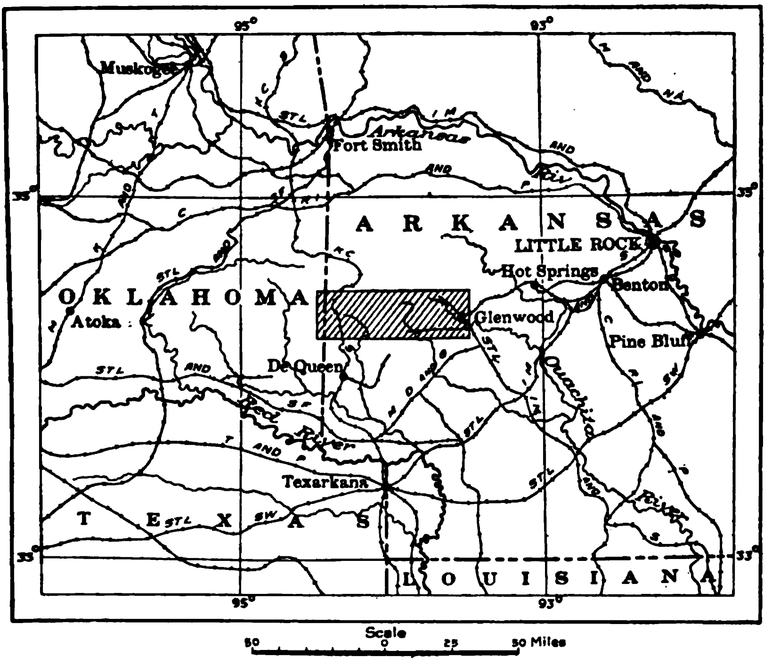

Figure 2.—Index map showing location of northern or mountainous parts of the Caddo Gap and De Queen quadrangles, Arkansas and Oklahoma.

Caddo Gap and De Queen quadrangles, in western Arkansas. The location of the mountainous districts of these quadrangles is shown in figure 2. Aside from their economic features, these deposits are of scientific interest, as they occur mainly at two definite horizons in the Arkansas novaculite, which is closely folded.

Below is given a list of papers treating of the manganese deposits of west-central Arkansas and the adjoining part of Oklahoma and some of the more important papers on the geology of the region:

Owen, D. D., Second report of a geological reconnaissance of the middle and southern counties of Arkansas, 1860.

The region containing the manganese deposits is described, but the existence of the deposits is not mentioned. The analyses given, however, show manganese in the soils and in some of the spring waters. An analysis of manganese ore from Batesville, in northern Arkansas, is given.

Anon., Age of steel, vol. 62, p. 9, St. Louis, Mo., September 3, 1887.

Contains an article on the manganese deposits of Polk County, together with analyses and a general description of the region.

Weeks, J. D., Manganese: U. S. Geol. Survey Mineral Resources, 1886–1892.

Short notices of the manganese ores of southwestern Arkansas, with several analyses.

Comstock, T. B., Report upon the geology of western-central Arkansas, with especial reference to gold and silver: Arkansas Geol. Survey Ann. Rept. for 1888, vol. 1, 1888.

Some manganese deposits are described and a number of analyses are given, but the principal purpose of the report was to present the results of an investigation of reported occurrences of gold and silver that had just caused considerable excitement in western Arkansas.

Penrose, R. A. F., jr., Manganese—its uses, ores, and deposits: Arkansas Geol. Survey Ann. Rept. for 1890, vol. 1, 1891.

Describes every known manganese region in North America. The report was prepared upon the general plan of discussing the uses of manganese, together with the history and statistics of the manganese industry, the ores of manganese, and the nature of the manganese deposits. The deposits of west-central Arkansas are described at length.

Griswold, L. S., Whetstones and the novaculites of Arkansas: Arkansas Geol. Survey Ann. Rept. for 1890, vol. 3, 1892.

The economic value, character, and origin of the novaculite are fully and ably treated; and the topography and geology of the novaculite area are described in detail and are represented on two colored maps. Although the manganese deposits are not described, the distribution and structure of the novaculite are shown on the two maps and are treated in the text. There are, however, three brief references to the manganese deposits, including a summary after Penrose.

Gurley, R. R., Geological age of the graptolite shales of Arkansas: Arkansas Geol. Survey Ann Rept. for 1890, vol. 3, pp. 401–423, 1892.

The first fossils found in the novaculite area are described and their age indications are discussed.

Ashley, G. H., Geology of the Paleozoic area of Arkansas south of the novaculite region: Am. Philos. Soc. Proc., vol. 36, p. 309, 1897.

Mentions small quantities of manganese ore in region described.

Purdue, A. H., The slates of Arkansas, Arkansas Geol. Survey, 1909.

The chapter on the geology of the slate area, which is partly in the Caddo Gap and De Queen quadrangles, describes for the first time the different rock formations to which names are applied. The distribution and structure of these formations in the mountainous portion of the Caddo Gap quadrangle are shown on a carefully prepared map. No mention is made of the manganese deposits, but the map especially is of value to prospectors, for it shows the structure and distribution of the Arkansas novaculite, in which the deposits are found.

Harder, E. C., Manganese deposits of the United States, with sections on foreign deposits, chemistry, and uses: U. S. Geol. Survey Bull. 427, pp. 119–122, 1910.

This report contains a good brief description of the manganese deposits of west-central Arkansas. The description given is a summary after Penrose.

Hewett, D. F., Manganese and manganiferous ores: U. S. Geol. Survey Mineral Resources, 1912, pt. 1, p. 219, 1913.

A number of manganese deposits in southeastern Oklahoma, adjoining the Arkansas region, are briefly described.

Joslin, G. A., Manganese in west-central Arkansas: Min. and Sci. Press, vol. 113, pp. 947–948, Dec. 30, 1916.

Describes briefly the manganese ores, methods of prospecting, and mining conditions.

No detailed report as a result of an examination of the manganese deposits of west-central Arkansas has appeared since the publication of Penrose's report in 1891. In the last quarter of a century knowledge of the geology of the region has been greatly increased, many new openings have been made, and some of the old ones have been reopened.

Practically all of the recently developed deposits were examined by the writer in the spring and summer of 1916, during the course of the field work for the De Queen-Caddo Gap folio, now being prepared by A. H. Purdue and him. No attempt was made to examine the undeveloped deposits. The region was visited at a favorable time, for the deposits were being prospected then and all the workings could be entered. The results of explorations that have been carried on since then will probably not materially affect the conclusions presented in this report. Penrose's report has been freely drawn upon for the description of such deposits as were not examined by the writer. The location of the deposits described by Penrose, as well as of those visited during the field work for this report, is shown on Plate III.

The information dealing with the general geology is the result of detailed field studies in the Caddo Gap, De Queen, and Hot Springs and vicinity quadrangles by A. H. Purdue, assisted by the writer and R. D. Mesler, in 1907; by Mr. Purdue, assisted by the writer, during the years 1908 to 1911; by the writer, assisted by Mr. Mesler, in 1912; and by the writer in 1913, 1914, and 1916. The field work in 1907 was done in cooperation with the Geological Survey of Arkansas.

The writer is under obligations to the people living within the area herein described and to the officials of the different mining companies for their uniformly courteous treatment. Among those to whom special acknowledgments are due for information are Messrs. S. A. Hanna and D. M. Nicholson, of Caddo Gap; Will Whisenhunt, of Shady; R. Lowery, W. E. Rainwater, and S. W. Sherrod, of Albert; H. L. Watkins and W. R. Sossamon, of Glenwood; Chester Stevens, of Hot Springs; C. L. French, consulting engineer for Edgar & Co.; N. H. Ohnsorg, manager of mines of the Mississippi Valley Iron Co.; G. A. Joslin, mining engineer for Dierks Lumber & Coal Co.; George Hammond, of Wickes; Robert Porter and W. R. Porter, of Fancy Hill; and Dallas Hollifield and M. A. Janes, of Hopper.

HISTORY.

The manganese deposits in west-central Arkansas have been worked only in a very small way, and up to the time of the completion of the present examination (Aug. 13, 1916) have yielded less than 200 tons of marketed ore. Most of the work has been done during two periods of activity, one beginning about 1885 and ending in 1889, and the other beginning in 1915 and still in progress. The earlier period occurred in the midst of the excitement over gold and silver that raged for a few years in west-central Arkansas, especially in Garland and Montgomery counties. The history of the exploitation of the manganese deposits at that time is summarized as follows by Penrose:[1]

> A great many places have been prospected, but the only considerable amount of work that has been done is on the land of the Arkansas Development Co. in Polk County, on the Brushy Creek branch of the Cossatot River. This company worked during the year 1888 and continued until April, 1889, when operations were suspended. A shaft was sunk to a depth of 142 feet, and a tunnel about 500 feet long was run in the side of a mountain. Many prospect openings were also made in the surrounding country from the headwaters of the Cossatot to those of the Saline River. About 20 tons of ore are said to have been taken out of the shaft on Brushy Creek, and this represented practically all the manganese that was mined by this company.
>
> About the same time the Capitol Land & Mining Co. carried on operations in Pulaski County, 12 miles west of Little Rock, in what is called the Fletcher Range. A few small prospect pits and tunnels were made, but no ore was shipped, and work has been discontinued.
>
> The only shipments of manganese ore known to have been made from the whole region were a few tons of the ore mined by the Arkansas Development Co., and 4 tons from a small pit on the Burns claim on North Mountain near

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[1] Penrose, R. A. F., jr., op. cit., p. 305.

the headwaters of the Little Missouri River. A sample of 500 pounds was also shipped by Mr. Webb Thornton from his claim on Leader Mountain, some 5 miles south of North Mountain.

Besides the above-mentioned localities, many small prospect pits have been made throughout the mountains wherever manganese crops out, but no ore has been shipped from them. Most of them have been made by the Arkansas Development Co. and by Mr. Burns.

The present mining operations are confined almost entirely to the mountainous districts in the northern parts of the Caddo Gap and De Queen quadrangles. The first work was done in August, 1915, by Chester Stevens, who mined and shipped 58 long tons of ore carrying 48.5 per cent of manganese from the Nelson mine, an open cut on Nelson Mountain 5 miles north of Glenwood, and 25 tons of ore from Pigeon Roost Mountain, 1½ miles from McKinley Crossing on the Memphis, Dallas & Gulf Railroad. Pigeon Roost Mountain is just east of the Caddo Gap quadrangle. Very little other work was done during 1915.

In March and April, 1916, F. P. Fay and Mr. Stevens prospected 14 lode-mining claims lying end to end along the crest of Leader Mountain, in the southeast corner of Polk County and the southwest corner of Montgomery County. These claims were later transferred to the firm known as Edgar & Co., of which Messrs. Fay and Stevens became members.

In May, 1916, Edgar & Co. established a mining camp on Little Missouri River in sec. 16, T. 4 S., R. 27 W., in Montgomery County and began prospecting in the vicinity. At the time of the writer's examination (July and August, 1916) the company had completed or partly completed five tunnels, and had made a number of shallow pits and cuts near the camp. It was also doing work in Pike County and was beginning work a few miles east of Caddo Gap, in Montgomery County.

In the spring of 1916 the Dierks Lumber & Coal Co. did a little work on a manganese deposit near the camp of Edgar & Co., but no ore was shipped.

In May, 1916, the Mississippi Valley Iron Co. began work on He Mountain and Coon Creek, in the southeast corner of Polk County. It has also done some work on Risner, Hogpen, and Redland mountains, near Langley, in the northwest corner of Pike County. The Still mine, on the southwest slope of Hogpen Mountain, had yielded 37 long tons of manganese ore at the time it was visited. This ore was hauled by wagons 20 miles to Glenwood, and thence shipped to the company's furnaces at St. Louis for testing. This company has also done some prospecting on Bear and Brushy mountains, 9 miles west of Glenwood. A letter from the company dated December 6, 1916, states that it had ceased operations at least temporarily.

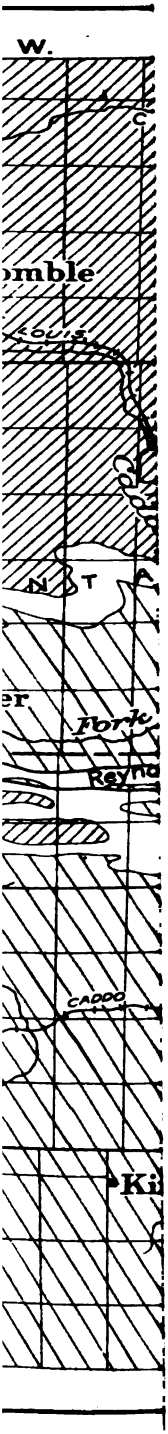
The activity of these individuals and companies has aroused much interest among the farmers and other people of this region, and many of them had prospected and were still prospecting their land and numerous mining claims in August, 1916.

GEOGRAPHY.

The manganese-bearing region under discussion embraces parts of Montgomery, Polk, Pike, and Howard counties in west-central Arkansas and a narrow strip of McCurtain County in southeastern Oklahoma. (See Pl. III.) It consists of two parts, in each of which the manganese deposits are confined to mountainous districts. The larger of the two parts is a belt 4 to 9 miles wide, extending westward across the northern part of the Caddo Gap quadrangle and into the northeast corner of the De Queen quadrangle. It includes much of the manganese-bearing belt described by Penrose. The other part, which is much smaller, is a belt 1 to 7 miles wide, extending from the west side of the De Queen quadrangle eastward halfway across the quadrangle. It is the east end of a mountainous area in the north-central part of McCurtain County, Okla., that contains manganese deposits, some of which are described in a forthcoming report by D. F. Hewett.

These mountainous districts are a part of the extensive system of ridges known as the Ouachita Mountains. In the area under discussion they are composed of groups of high ridges separated on the south from the Coastal Plain by a dissected piedmont plateau, highest at the north, which stands 750 to 1,100 feet above sea level. The ridges are high, narrow, and nearly parallel and trend in general east and south of east. They are separated by valleys of similar magnitude, which in most places extend parallel with the ridges but in others cut through them in gorgelike water gaps. The ridges have steep, rugged slopes and sharp, even crests, a few hundred feet above which rise a great many peaks, and they commonly range from 500 to 1,000 feet above the adjoining valleys and the piedmont plateau. Most of the ridges range from 1,500 to 2,000 feet above sea level, but several are higher. Raspberry Peak, the highest point, rises to an altitude of 2,360 feet. Other prominent peaks are Tall Peak, East Hanna Mountain, West Hanna Mountain, Eagle Mountain, High Point, and Whisky Peak, in the De Queen quadrangle; and Brushheap, Hogpen, Hightop, Tweedle, Wilson, and Straw mountains, in the Caddo Gap quadrangle.

The mountains are very rough, the slopes are steep, and rock ledges are numerous. There are, however, no large surfaces of bare rock except along the crests of some of the higher ridges and in the water gaps, and cliffs are not very numerous. The slopes, whe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not occupied by bare ledges, are covered by talus, much of which is boulders.

The principal streams are Caddo, Little Missouri, Saline, and Cossatot rivers, all of which rise in the mountains in the area under discussion and flow southward or southeastward beyond its borders, the first two entering Ouachita River and the last two Little River.

Except for small tracts that have been cleared and put under cultivation, the region is densely forested, and much of it is included in the Arkansas National Forest. Public and secondary roads reach all parts of the area, but only a few of them are maintained in good condition. They keep to the valleys in the mountainous districts and cross the mountains only through water gaps and saddles. Some of the roughest portions of the area are reached by means of trails, many of which have been constructed by the Forest Service.

The Kansas City Southern Railway traverses the west end of the region herein described from north to south, and a branch of the St. Louis, Iron Mountain & Southern Railway penetrates its east end, passing through Rosboro, Glenwood, and Caddo Gap and terminating at Womble. The Caddo & Choctaw Railroad extends from Rosboro westward to Cooper Junction, a distance of 14 miles. From Cooper Junction a logging spur of the Caddo River Lumber Co. penetrates as far as a point on Little Missouri River 2 or 3 miles south of Langley, and an extension of this spur to a point within 1¼ miles of the Still mine was being planned at the time of the writer's examination. The Memphis, Dallas & Gulf Railroad passes through Glenwood, but from that place southeastward as far as Shawmut its trains run over the track of the St. Louis, Iron Mountain & Southern Railway. Some of the mines and prospects, whose location is also shown on Plate III, are near railroads, but many are as far as 25 to 30 miles away.

GEOLOGY.

STRATIGRAPHY.

GENERAL FEATURES.

The geologic formations in the region here described are Paleozoic, ranging from Cambrian to Carboniferous. The Arkansas novaculite contains the manganese deposits and is the most conspicuous formation in the region. It is thus the only formation whose detailed description need be given in this report.

The succession of formations, together with the principal features of their lithology, is outlined in the following table:

Generalized section of the Paleozoic rocks of the Caddo Gap and De Queen quadrangles, Arkansas and Oklahoma.

System.	Formation.	Thickness (feet).	Character.
Carboniferous.	Atoka formation.	6,000+	Hard micaceous ripple-marked light-gray to greenish-gray sandstone interbedded with equal amount of sandy micaceous black clay shale.
	Jackfork sandstone.	5,000-6,600	Massive compact fine-grained to coarse-grained light-gray sandstone with some millstone grit, especially in the basal part. Indeterminable invertebrate fossils found in millstone grit at base. Green fissile clay shale constitutes a very small part of formation. Exposed in low pine-clad ridges.
	Stanley shale.	6,000	Bluish-black and black fissile clay shale and fine-grained compact greenish-gray or bluish-gray sandstone. Beds of novaculite conglomerate at and near base. Beds of graywacke near base in western part of De Queen quadrangle. Some shale at base has in places been altered to slate, to which the name "Fork Mountain slate" has been earlier applied. Upper part of formation has yielded a single collection of plants, including some ferns. Quartz veins contain lead, zinc, and antimony minerals in De Queen quadrangle.
	—Unconformity—		
Devonian (?). Devonian.	Arkansas novaculite.	250-950	Consists of three lithologic divisions—a lower one, made up almost entirely of massive white novaculite, at whose top is one of the two manganese horizons; a middle one, consisting mainly of thin layers of dense dark-colored novaculite interbedded with shale and having a conglomerate of local distribution at the base; and an upper one, consisting chiefly of massive, highly calcareous novaculite, which also yields manganese. The lower division is of lower Oriskany (Lower Devonian) age, and the middle and upper divisions are tentatively assigned to the Upper Devonian. These correlations are more fully discussed on pages 70-71.
Silurian.	Missouri Mountain slate.	50-300	Red and green clay slate. No fossils have been found, and the assignment to the Silurian system is therefore based on its lithologic character and stratigraphic relations.
	—Unconformity?—		
	Blaylock sandstone.	0-1,500	Fine-grained light-gray to dark-gray or green compact hard sandstone and buff to dark shale. A collection containing seven species of graptolites was obtained at the south base of Blaylock Mountain. These species, as pointed out by E. O. Ulrich, are not comparable to any described from America but have all been described from the Birkhill shales of Scotland, which are in Britain considered the base of the Silurian system. He thus assigns the Blaylock to the Silurian system.
	—Unconformity?—		

Generalized section of the Paleozoic rocks of the Caddo Gap and De Queen quadrangles, Arkansas and Oklahoma—Continued.

System.	Formation.	Thickness (feet).	Character.
Ordovician.	Polk Creek shale.	0-175	Black graphitic shale; in parts siliceous and in others clay shale. Graptolites are abundant.
	Bigfork chert.	700	Thin-bedded gray to black much shattered chert interbedded with thin layers of black shale. Fossils consist mainly of graptolites.
	Womble shale.	1,000	The Womble shale receives its name from the town of Womble, part of which is on the base of this shale. Much of the shale to which this name is now applied was in 1909 regarded by Purdue[a] as a part of his "Ouachita shale," which as defined comprised the rocks between the Crystal Mountain sandstone below and the so-called Stringtown shale above. A sandstone, now called the Blakely sandstone, that was in 1909[a] regarded as the upper part of the Crystal Mountain sandstone, has since been determined by Purdue and the writer to occur in the middle of the "Ouachita shale." The use of the name Stringtown has been discontinued in this area because the beds to which it was applied do not form a mappable unit distinct from the rest of the shale above the Blakely sandstone; because the graptolites supposed to be characteristic of it have apparently been found well down in the underlying shale; and because, according to E. O. Ulrich, the limits and character of the Stringtown shale at the type locality in Oklahoma are in doubt. With the recognition of the Blakely sandstone as a distinct formation and the failure to separate the Stringtown it became necessary to give a new name (Womble shale) to the whole interval between the Blakely sandstone and the Bigfork chert. The name "Ouachita shale" is abandoned because its limits are not the same as those of any one of the units now mapped, and because Ouachita has the same pronunciation as Washita, the well-established name of the upper group of the Comanche series. The formation consists of black graphitic shale with thin beds of sandstone near the base and beds of limestone near the top. The shale near the base is composed of black and green layers that split at an angle with the bedding and thus show ribboned cleavage surfaces. Graptolites of Lower Ordovician age are numerous.
	Blakely sandstone.	0-400	The Blakely sandstone takes its name from Blakely Mountain, in Garland County, Ark., from which it is continuously exposed as far west as Womble, where it thins out, thus permitting the Womble and Mazarn shales to come together west of that town. It consists of shale in alternating black and green layers and hard gray sandstone. The shale constitutes 75 per cent of the whole, but the sandstone, which produces ridges, is the prominent feature. Graptolites of Lower Ordovician age found only in Blakely Mountain.

[a] Purdue, A. H., The slates of Arkansas, pp. 30, 33-35: Arkansas Geol. Survey, 1909; (abstract) U. S. Geol. Survey Bull. 430, pp. 321-325, 1910; (abstract) U. S. Geol. Survey Prof. Paper 71, pp. 160-162, 1912.

Generalized section of the Paleozoic rocks of the Caddo Gap and De Queen quadrangles, Arkansas and Oklahoma—Continued.

System.	Formation.	Thickness (feet).	Character.
Ordovician—Con.	Mazarn shale.	1,000	The Mazarn shale takes its name from Mazarn Creek, whose headwaters are in the northeast corner of the Caddo Gap quadrangle. The name is applied to the part of the "Ouachita shale" lying below the Blakely sandstone. The formation consists of shale and of small amounts of limestone and sandstone. The shale is ribboned, consisting of alternating black and green layers that split at an angle with the bedding. Graptolites of Lower Ordovician age have been found.
Ordovician (?).	Crystal Mountain sandstone.	850	Coarse-grained massive gray to brown sandstone, calcareous in places. A conglomerate at the base contains limestone and chert pebbles derived from the Collier shale. The formation has not yielded any fossils. Owing to its stratigraphic relations and lithologic character, it is tentatively assigned to the Ordovician system. Clusters of quartz crystals are found in fissures at numerous places, and many are sold at Hot Springs, Ark., to museums and for use as ornaments.
	—Unconformity—		
Cambrian.	Collier shale.	200+	Bluish-black soft graphitic, intensely crumpled clay shale, some limestone, and a few thin layers of dark chert. Has yielded no fossils. Assigned to the Cambrian because it unconformably underlies the Crystal Mountain sandstone, which in turn underlies the Mazarn shale, of Lower Ordovician age.

ARKANSAS NOVACULITE.

The Arkansas novaculite in the Caddo Gap and De Queen quadrangles, as in other parts of the Ouachita Mountains, is exposed in more or less parallel and nearly eastward-trending belts, whose narrowness is due to the steep dips of the beds. Owing to the narrowness of these belts and to the greater resistance of the novaculite to weathering than the adjacent strata above and below, its outcrops stand up as sharp ridges, whereas both the older and the younger rocks form intervening valleys. The mountainous districts of the quadrangles thus present a corrugated surface when viewed from a high point.

Because of the brittleness of the novaculite and of its numerous joints, it breaks down into angular blocks of large and small size and forms a surficial material that covers the ridges in most places; but in others, particularly along the crests and in the water gaps, the edges of the beds project in rough, bare ledges through the débris. Some of these ledges stand up in walls several feet high along the crests.

The Arkansas novaculite is thickest in its southernmost outcrops, where the thickness at many if not at most places is about 900 feet.

The greatest known thickness, 950 feet, was measured 1 mile west of West Hanna Mountain. At Caddo Gap the formation is about 890 feet thick. It thins toward the north and along the northern border of the area is about 250 to 300 feet thick. This thinning finds expression in the lower elevation of the ridges toward the north. In the Cross Mountains, on the west side of the De Queen quadrangle, the formation is 540 feet thick.

In the Caddo Gap and De Queen quadrangles and many other parts of the Ouachita Mountains the formation consists of three lithologic divisions—a lower one, made up almost entirely of massive white novaculite; a middle one, consisting mainly of thin layers of dense dark-colored novaculite interbedded with shale; and an upper one consisting chiefly of massive, highly calcareous novaculite. The manganese is found at the top of the lower division and in the upper division. These divisions vary in thickness and character from place to place.

The lower division is commonly from 150 to 300 feet thick, though at some places the thickness is greater; the maximum of 410 feet is at Caddo Gap, and the minimum of 25 feet is in the extreme northeast corner of the De Queen quadrangle. This division is made up almost wholly of typical novaculite, whose white color and massiveness make it the most conspicuous part of the formation. In fact, it is this part that usually occupies the crests of the ridges. The beds are from 2 to 10 feet thick and are commonly even bedded, though in places some of the novaculite occurs in thin lenses and nodules. Some of the exposed bedding planes show large uneven ripple marks. At a number of places beds of red, buff, and, less commonly, black and green shale, reaching 15 feet in thickness, are interbedded with the basal layers of this division of the formation.

The massive novaculite is usually dense, gritty, fine grained, homogeneous, highly siliceous, translucent on thin edges, and white with a bluish tint, but where unweathered it is bluish gray. It has an uneven to conchoidal fracture and a waxy luster like that of chalcedony. Though the bulk of the rock is white, much of it varies in shades of red, gray, green, yellow, and brown, and in many places it is black. These shades are produced by iron and manganese oxides and possibly in some places by carbonaceous matter. The darker colors are prevalent in the lower 50 to 75 feet. In parts, especially near the base, the rock shows a fine parallel lamination, and much of it contains a few cavities that are oval in cross section and half an inch in their longest dimension, besides others of less size and of irregular shape. The rock contains a little calcite, but exposures of the calcareous stone are not common and have been found only in stream beds. Joints are numerous and run in all directions, but the most prominent joints are normal to the bedding. Many of them are filled by white quartz veins which are usually so thin as to be inconspicuous. Slickensides along both joints and bedding planes are common.

The middle part of the formation consists chiefly of interbedded novaculite and shale. The novaculite is similar to that in the lower massive part of the formation, except that the common color is dark gray to black and that the beds are much thinner, usually between 1 inch and 6 inches thick. Moreover, some thin layers are argillaceous and have a fairly good cleavage, resembling in these respects a highly siliceous shale. The whole division is cut by many joints, some of whose faces are so smooth they look as if they had been polished. A conglomerate at the base of this division was observed at a number of places. It consists of small rounded and subangular pebbles of novaculite in a sandy and dense flinty matrix. The shale ordinarily observed is black, weathering to a buff or brown color, but some of it is red. It is in beds from a fraction of an inch to 70 feet thick. As a rule, it is fissile argillaceous shale, but at some places it has been hardened to slate. Much of it strongly resembles the lower part of the Stanley shale.

The upper part of the formation ranges from about 20 to 125 feet in thickness and is thickest along the southernmost exposures. It consists chiefly of massive, highly calcareous light-gray to bluish-black novaculite which is so resistant that at some places where it and the accompanying beds of the formation are not overturned it produces low ridges or knobs on the slopes of the higher ridges. Some thin beds of ordinary dense chalcedonic novaculite like that so characteristic of the middle and lower parts of the formation are also included. Fine lamination parallel with the bedding is common. On weathering, the more calcareous rock loses its calcium carbonate, becomes white or cream-colored and porous and soft enough to receive impressions from the hammer without breaking, and shows a great many oval and irregular-shaped cavities like those in the basal division of the formation. Some of these cavities are due simply to the removal of calcium carbonate through solution, but others appear to have a different origin and may be casts of poorly preserved shells. Although some dense, hard novaculite is present at most if not all places where this division of the formation is exposed, it becomes less calcareous and more siliceous toward the north, and at some localities it consists entirely of novaculite like that in the basal division of the formation.

The only remains of animals thus far found in the formation consist of numerous conodonts in a minutely pebbled novaculite conglomerate and of conodonts and small linguloids and sporangites in associated shale, which have been obtained from the middle division of the formation at Caddo Gap. Upon them E. O. Ulrich bases the opinion that the middle and upper divisions of the formation are to be correlated with the Woodford chert in the Arbuckle Mountains in southern Oklahoma and with the Chattanooga shale. He assigns these two formations to the Mississippian series of the Carboniferous and accordingly regards the middle and upper divisions of the Arkansas novaculite as belonging to that series, but the United States Geological Survey tentatively places these two divisions of the novaculite in the Upper Devonian. The lower division is separated from the middle one by an unconformity of at least local extent and, by its lithologic character and stratigraphic relations, is correlated with the Camden chert of western Tennessee, which is known by its fossils to be of lower Oriskany (Lower Devonian) age.

STRUCTURE.

The beds of the Arkansas novaculite are rarely horizontal but are inclined at various angles so that their edges appear at the surface. When they are crossed from north to south they are found to lie in a series of anticlines (arches) and synclines (troughs), and in a few places they have suffered displacement by faults.

The Caddo Gap and De Queen quadrangles contain two areas where the oldest rocks have been uplifted through folding and now stand as high as the youngest. One of these areas includes the mountainous portion of the Caddo Gap quadrangle and the northeast corner of the De Queen quadrangle. This is a part of the west end of the Ouachita anticline, which is the prominent fold of the Ouachita region in Arkansas. The other area includes the Cross Mountains, in the western part of the De Queen quadrangle. It is the east end of the Choctaw anticline, which is the most prominent fold of the Ouachita region in Oklahoma.

These large folds are composite and are thus essentially anticlinoria. Some of their larger subdivisions can be followed for long distances; but the single folds, some of which are represented in figures 3 and 4, are narrow, overlap one another lengthwise, and can be traced only a few miles along their axes. They all have the same general direction as that of the ridges and thus bear a close relation to the topography, for outcropping edges of the hard strata upturned on the folds have formed the ridges and the softer intervening strata underlie the valleys. Their general trend does not greatly depart from west, but it is north of west in the Ouachita anticline, west in the Choctaw anticline, and south of west in the piedmont plateau. Many adjacent folds are of nearly the same height, and the same beds are repeated many times at the surface. The dip gradually changes in amount from place to place along the strike, and on some of the folds it even changes in direction within a mile. These changes may take place where a single fold breaks up into two or a symmetrical fold is closely compressed so that the strata are parallel. Two structure sections of the same mountain or valley only a mile apart might therefore be very different. Scarcely any two ridges are alike in structure, and some of them, especially many high peaks, are composed of two or three lesser anticlines with their intervening synclines. The sides of most of the folds have been compressed until they are parallel, the rocks on one side having been turned through an angle exceeding 90°, so that the beds on the two sides of the fold dip in the same direction. The dips of the overturned rocks are in places as low as 40°. This means that the rocks in such places have been turned through an angle of 140°. In some parts of the area the pressure that produced such overturning was exerted from the north; in other parts from the south. As a rule the folds are smallest, most numerous, and most closely squeezed in the shales and thin-bedded sandstones and chert. Joints in several sets and slickensides are common in all the rocks but are most numerous in those just named.

Faults are common, though less so than might be expected in strata that have been so closely compressed as these. This is due to the great predominance of thin-bedded strata over massive, rigid beds like the Crystal Mountain sandstone, Arkansas novaculite, and Jackfork sandstone, in consequence of which the beds as a whole bent rather than broke under stress. About thirty faults have been mapped in the two quadrangles, and others, which doubtless exist, may be detected in future work. The faults were produced by the breaking and overthrusting of strata in closely compressed anticlines. So far as observed, all the faults are thrust faults, with the exception of one small normal fault in the SW. ¼ sec. 31, T. 3 S., R. 26 W. The direction of the faults, therefore, is in the main east or parallel with the ridges. The length of the longest ones does not exceed 12 miles, and most of them are much shorter. The dip of all the fault planes is high; some of them dip south and some north. The dislocation ranges, even along a single fault, from a few feet to several hundred or a few thousand feet or more, but only a minimum measure is obtainable anywhere.

As may be seen by reference to Plate III, a large number of the faults occur near the north border of a group of mountains extending westward from the vicinity of Glenwood. This is, in fact, the principal zone of faulting in the area. It extends south of east from the valley of Sugar Creek, in the De Queen quadrangle, passing south of Fancy Hill, in the Caddo Gap quadrangle, and eastward along the valley of South Fork, apparently terminating near Caddo River.

Many structural details are mentioned in the descriptions of the mines and prospects, beginning on page 85.

ORE DEPOSITS.

CHARACTER OF ORES.

The manganese ores of the Caddo Gap and De Queen quadrangles consist of oxides, four of which, psilomelane, pyrolusite, manganite, and wad, have been identified; if others are present, they probably occur in minute quantities. Although these minerals may be found separately, as a rule two or more are intimately mixed in the same deposit, and in some places they are associated with iron ores and manganiferous iron ores. Psilomelane, pyrolusite, and manganite form the larger part of the manganese ore in this region. A material consisting of rock fragments and clay cemented together by soft manganese oxide is present at a number of places; locally it is known as "bog ore." Descriptions of these minerals follow.

Psilomelane is a black or steel-blue mineral that breaks with a conchoidal fracture, shows in places botryoidal surfaces, and occurs in the amorphous form and with a massive, concentric, or stalactitic structure. It has a specific gravity of 3.7 to 4.7 and a hardness of 5 to 6, which means that a knife blade scratches it with difficulty, if at all. The chemical composition of psilomelane is not definite; potash, baryta, and water occur in it in varying amounts and are supposed by some mineralogists to be mechanically admixed. An analysis of psilomelane is given below.

Pyrolusite is a grayish-black to black mineral with a crystalline or granular structure and a black or bluish-black streak. It has a hardness of 2 to 2.5, being much softer than psilomelane and a specific gravity of 4.8. Pure pyrolusite contains 63.2 per cent of metallic manganese, but the mineral is usually impure, as is shown in the accompanying analysis. This mineral was identified by Penrose as occurring in the area under discussion but was not detected by the present writer, though it is possible that a small quantity of the manganite described herein is pyrolusite.

Analyses of psilomelane and pyrolusite from the Caddo Gap and De Queen quadrangles.[a]

[R. N. Brackett, analyst.]

	Psilomelane.[b]	Pyrolusite.[c]
MnO	73.17	76.90
O	15.11	16.66
Fe_2O_3	.26	1.06
Al_2O_3	6.53	.79
CoO	Tr.	Strong tr.
CaO	1.58	.52
BaO	.05	2.83
MgO	....	.14
K_2O	2.12	.26
Na_2O	2.35	.20
P_2O_5	Tr.	....
SiO_2	.15	[d] 1.52
	101.31	99.88

[a] Penrose, R. A. F., jr., Manganese—its uses, ores, and deposits: Arkansas Geol. Survey Ann. Rept. for 1890, vol. 1, pp. 314-315, 1891.

[b] North Mountain in southwestern Montgomery County.

[c] Cossatot Mountain, in southeastern Polk County.

[d] Includes insoluble matter.

Manganite is a black brittle massive or crystalline mineral with a reddish-brown or nearly black streak. It has a specific gravity of 4.2 to 4.4, a hardness of 4, and a theoretical content of 62.4 per cent metallic manganese and 10 per cent water. It occurs generally with psilomelane in alternating layers in botryoidal masses. In such masses it consists of numerous needles that radiate from the walls toward the middle of the vein. Locally crystals of manganite are scattered through masses of psilomelane or occupy the centers of stalactite-like rods of psilomelane, the association being such as to lead to the conclusion that manganite is an alteration product of psilomelane.

Wad, an impure mixture of manganese oxides, is a soft dark-brown or black earthy mineral occurring with psilomelane and manganite or by itself. At a few places it occurs in alternating layers with psilomelane in botryoidal masses. Dendrites, branching moss-like growths of wad, are common along joints in the novaculite.

The iron ores comprise various hydrous sesquioxides, of which limonite is probably the most abundant. The mineralogic species of the iron oxides found in each deposit in the area have not, however, been determined, and the materials are called simply brown or red iron oxides. By some people these are mistaken for manganese oxides. Iron pyrites in veinlets and minute scattered crystals is common in the unweathered portions of the novaculite. One of the places where it was noted is the lower tunnel at the North Mountain mine, in sec. 10, T. 4 S., R 27 W.

The most abundant material with which the iron and manganese ores are associated is clay, some of which has been brought in by ground water and some of which is residual and probably in place. Minute quantities of dufrenite, a green mineral composed of phosphorus pentoxide, iron sesquioxide, and water, and usually occurring in globular aggregates with a radial structure, occur in a few of the prospects. Thin layers of opal are associated with weathered dufrenite at the Missouri Mountain prospect and the Tellus Davis prospect No. 2. Films of chalcedony in which are small particles of native copper were found in the lower tunnel at the North Mountain mine. This chalcedony is stained bluish green by a minute quantity of chrysocolla, a copper silicate combined with some water. Films of similar chalcedony were found on claim No. 7 on Leader Mountain.

OCCURRENCE OF ORES.

The manganese ores occur as nodules, pockets, and short irregular veins from a fraction of an inch to 4 feet thick. Thicknesses of 4 feet, however, are rare, and those of a foot are not common. The ore bodies are scattered through the hard novaculite, and can doubtless be found on every mountain where the Arkansas novaculite is exposed. The ores occupy bedding planes or joint cracks or form a cement in a novaculite breccia, in which the rock fragments range from a fraction of an inch to over a foot in diameter. The iron and manganese ores may be intimately mixed in the same pocket or vein, they may occur separately in different parts of the same vein, or they may occur in separate masses. Most of the ore is confined to two stratigraphic horizons in the Arkansas novaculite. One of these is in the upper division of the formation and the other is near the top of the lower division. Some deposits, however, such as those at the North Mountain mine, the Fagan mine, and the Eureka, Rattlesnake, S. A. Hanna, and R. M. Cogburn prospects, are found in other parts of the lower division, and the geologic position of some others was not determined.

The Arkansas novaculite and other formations have been thrown into a series of folds whose trend is parallel with the ridges. This formation is very resistant; the upturned edges stand up as ridges on which rock ledges or their débris abound. The beds at the two ore horizons, which show ore at the surface in many places, may thus be followed for long distances along the slopes, and their outcrops, owing to the numerous folds, are repeated on the slopes or crests of the many parallel ridges, or even on a single ridge. The outcrops of these ore-bearing beds are sometimes called "lodes" or "leads."

The accompanying section (fig. 3) through Leader, Brier Creek, Sugartree, and Statehouse mountains, on or near which extensive

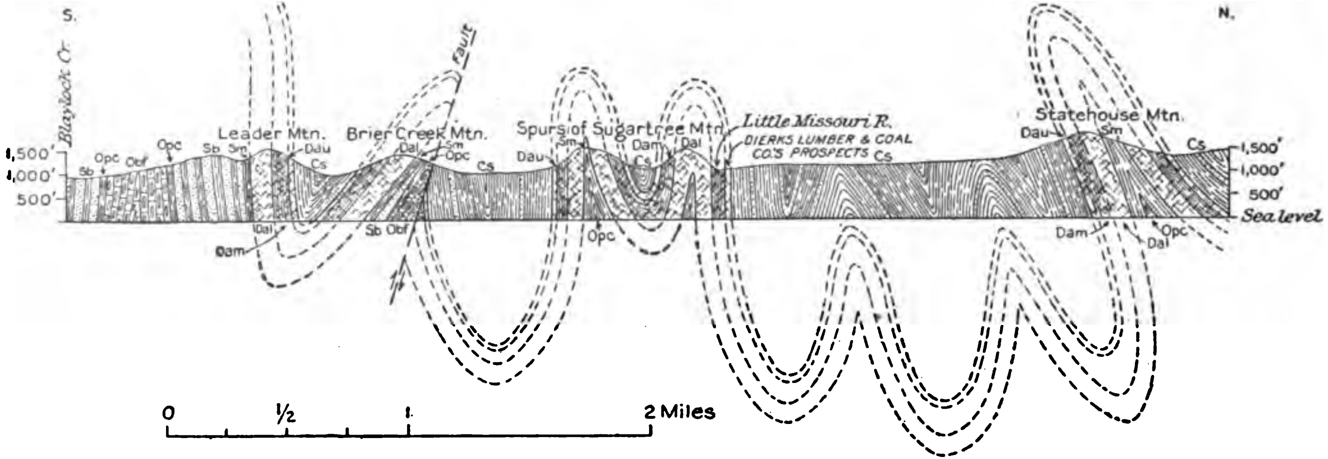

Figure 3.—Section along line C–D on Plate III, through the east ends of Leader, Brier Creek, and Sugartree mountains and the west end of Statehouse Mountain, Montgomery County, Ark., showing the folding of the Arkansas novaculite. Cs, Stanley shale; Dau, upper division of Arkansas novaculite, upper manganese horizon; Dam, middle division of Arkansas novaculite; Dal, lower division of Arkansas novaculite (lower manganese horizon is at the top of this division); Sm, Missouri Mountain slate; Sb, Blaylock sandstone; Opc, Polk Creek shale; Obf, Bigfork chert. The probable underground structure of the Arkansas novaculite below sea level is represented by the broken lines in the lower part of the figure, and the probable structure of the novaculite before it was eroded down to the present level is represented by the broken lines in the upper part.

prospecting for manganese is going on, illustrates the way in which the beds of the two manganese horizons are repeated on different ridges. Many other ridges are similar in structure to those shown in the section; but others, as well as different parts of the same ridge, are different. The structure of some is complicated; for example, that of East Hanna Mountain, a high peak in sec. 34, T. 4 S., R. 29 W., 3 miles east of Cossatot River. (See fig. 4.)

These sections represent the structure as it is inferred from the position of the beds observed at the surface and are on too small a scale to show all the minute structural details.

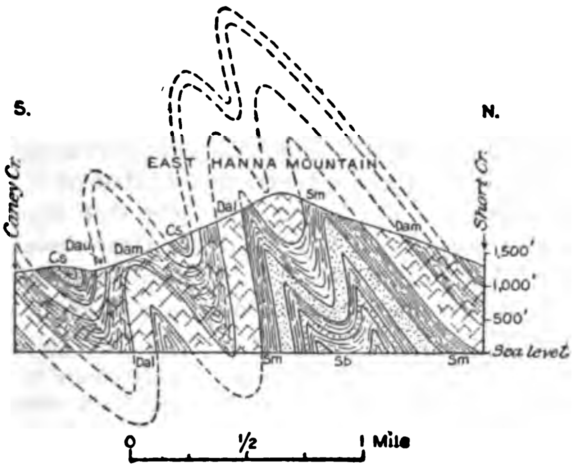

FIGURE 4.—Section along line A–B on Plate III, through East Hanna Mountain, Polk County, Ark., showing the folding of the Arkansas novaculite. Cs, Stanley shale; Dau, upper division of Arkansas novaculite; Dam, middle division of Arkansas novaculite; Dal, lower division of Arkansas novaculite; Sm, Missouri Mountain slate; Sb, Blaylock sandstone.

The beds at the two manganese horizons, as shown in figure 3, occur on Leader Mountain, those at the lower horizon on the crest and those at the upper horizon on the north slope. The prospected manganese deposits on this mountain are in the beds at the lower horizon.

The two horizons are represented on the south slope of Brier Creek Mountain, the upper beds being lower on the slope than the lower beds, but neither horizon is represented on the north slope, owing to the presence of a fault that has been produced by the breaking of the strata in a closely compressed anticline. No prospecting has been done on this mountain. Penrose,[1] however, states that "A stain of iron and manganese and occasionally small masses of the ores occur in the gray novaculite on the part of the mountain lying in Polk County, and probably these same occurrences extend into Montgomery County; but no important quantity of either ore was seen."

Both horizons are represented at two places on or near each of the two eastward spurs of Sugartree Mountain, as the structure of the spurs is anticlinal. A manganese deposit at the upper horizon has been revealed in the Dierks Lumber & Coal Co.'s prospect near the north base of the north spur, and others at both horizons have been found in the Rainwater prospects and the Sugartree Mountain prospects, farther west on Sugartree Mountain.

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[1] Penrose, R. A. F., jr., Manganese—its uses, ores, and deposits: Arkansas Geol. Survey Ann. Rept. for 1890, vol. 1, p. 857, 1891.

Both horizons are also twice represented on the part of Statehouse Mountain through which the section is made. A manganese deposit that is being explored by Edgar & Co., about half a mile east of the line of the section, is at neither horizon but is near the base of the formation. The structure at that place (fig. 9, p. 100) is different from that shown in figure 3. Other deposits on this mountain not visited by the writer are described by Penrose (pp. 102–103). Their stratigraphic position in the Arkansas novaculite is not known.

The structure of East Hanna Mountain, shown in figure 4, is more complicated than that of any of the mountains just described; it comprises three anticlines and the two intervening synclines.

The above-described sections and that of Penrose,[1] illustrating the occurrence of the manganese ores and reproduced by Griswold[2] and in part by Harder,[3] agree in their essential features, but Penrose's section is incorrect in its detail and shows manganese-bearing beds at only one horizon, concerning which he says:[4]

> The rock carrying the manganese represents an interbedded stratum in the upper part of the gray novaculite, usually occurring at or near the contact of that bed with the overlying gray and black siliceous shale. Similar ores probably sometimes occur in small quantities in the lower part of the novaculite, but they are of no importance.

The section by Penrose was made across two parallel ridges 1 mile east of Cossatot River, separated by Short Creek. The southern ridge he called "East Hannah Mountain" and the northern one "Shadow Rock Mountain." On the topographic map of the De Queen quadrangle no name is given to "Shadow Rock Mountain," the name "East Hanna Mountain" is applied to a peak 3 miles east of Cossatot River, and the name "Hanna Range" is applied to the "East Hannah Mountain" of Penrose. The Hanna Range, 1 mile east of Cossatot River, is made up of three anticlines and the two intervening synclines, and the structure of the unnamed ridge ("Shadow Rock Mountain" of Penrose) is monoclinal, with the oldest rocks exposed on the north slope.

Deposits that bear certain definite relations to the structure of the Arkansas novaculite occur at the following places. The deposits at the Nelson mine, Fields prospect, Watkins-White prospects, Janes prospects, Brushy Mountain prospects, and North Mountain mine are on or near the noses of plunging anticlines; the deposit at the Bear Mountain prospect is exactly on the axis of an anticline; that at the S. A. Hanna prospect is along a fault; and that at the Eureka prospect is near a fault.

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[1] Penrose, R. A. F., jr., op. cit., p. 322.

[2] Griswold, L. S., Whetstones and the novaculites of Arkansas: Arkansas Geol. Survey Ann. Rept. for 1890, vol. 3, p. 261, 1892.

[3] Harder, E. C., Manganese deposits of the United States, with sections on foreign deposits, chemistry, and uses: U. S. Geol. Survey Bull. 427, p. 120, 1910. The horizontal scale of the figure given by Harder is incorrect; the number of miles should be read as tenths instead of whole numbers.

[4] Penrose, R. A. F., jr., op. cit., p. 321.

The depth to which the ore extends is not known. An 8-foot vein of solid manganese ore is, however, reported to have been found in the lower tunnel at the North Mountain mine at a distance of about 615 feet from the portal. This tunnel is 250 feet above the road along the south base of North Mountain; it is 530 feet below the crest of the mountain and is 216 feet below the upper tunnel, which penetrates the exposed ore body near its main outcrops. At other places ore is found only in the present shallow workings. These workings and the outcrops of ore occur at all altitudes on the high ridges, from the level of the streams that cut through them up to their crests, which are even and probably represent a Cretaceous peneplain. The deposits examined by the writer range from 900 to 1,800 feet above sea level, but the greatest difference in altitude in any single locality is about 800 feet. This range does not necessarily mean that a shaft sunk from the crest of a mountain would find ore at a depth of 800 feet or that a tunnel driven into the base of a mountain 800 feet below its crest would find ore, for the lower limit of the ore, which may not extend much below water level, may be higher in the mountains than in the valleys, just as the water level is higher in the mountains than in the valleys. It appears probable, however, that the ore extends downward some distance—say 200 or 300 feet—below the water level. In Virginia and Maryland, as pointed out by Hewett,[1] manganese ore is mined to a depth of 220 feet below the water level.

ORIGIN.

The occurrence of the manganese ores in the Arkansas novaculite suggests that their origin and that of the novaculite are intimately associated. Penrose[2] has expressed the opinion that they were deposited at the same time as the novaculite, a rock which is regarded by the present writer and some others as having been deposited through chemical or organic processes, or both, and thus belonging to the class of cherts.

That manganese, as finely disseminated particles, was deposited with the silica that formed the novaculite at the two main ore horizons is indicated by partial analyses made by George Steiger, of the United States Geological Survey. A specimen of unweathered calcareous novaculite from the top of the basal division of the formation on Little Missouri River, near the east line of sec. 16, T. 4 S., R. 27 W., contains 0.084 per cent of manganous oxide (MnO), and a specimen of similar novaculite taken from the upper division in the old Sugartree tunnel, at the north base of Sugartree Mountain, contains 0.022 per cent. At both these localities a black oxide of manganese penetrates and partly replaces the novaculite along cracks, but the material analyzed was free from veins and stains of such oxide. It seems probable that much of the manganese ore of the deposits herein described was derived from this finely disseminated manganese by processes of solution, segregation, and redeposition during the erosion of the mountains down to their present level. Whether or not the manganese originally deposited with the novaculite was less abundant in other parts of the formation is not known, but the occurrence of most of the deposits at the two horizons mentioned suggests that a greater quantity of manganese was originally deposited there than elsewhere in the formation, or that these two parts of the formation have later offered the most favorable places for the deposition of manganese from outside sources.

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[1] Hewett, D. F., Some manganese mines in Virginia and Maryland: U. S. Geol. Survey Bull. 640, pp. 63–64, 1916.

[2] Penrose, R. A. F., jr., op. cit., p. 325.

Some of the manganese ores here described may have been derived from other parts of the Arkansas novaculite, from the underlying Missouri Mountain slate, or from the overlying Stanley shale, the last two of which contain minute quantities of manganese.[1] Had the bulk of the ores been concentrated from the rocks just mentioned, however, manganese deposits would have been formed in the Arkansas novaculite at any place structurally favorable for deposition. It is believed by the writer that the two manganese horizons of the Arkansas novaculite, except as regards supply of material, offer no more favorable places for the deposition of ore than other parts of the formation. The middle division, however, which contains much shale, is relatively impervious, and thus would not permit the free circulation of ore-bearing solutions.

The concentration of the ores has been effected by ground water, which has carried down their constituents from the vast mass of rock that has been eroded from the region. The local concentration of the ores into deposits large enough to be of value appears to have been dependent upon the amount of open space in the Arkansas novaculite, which is hard and compact and usually has no visible openings between the layers or along the joints. The places where fissures are largest and most numerous would be most favorable for the circulation of underground water, and consequently for the deposition of the ore, little of which replaces the novaculite. The fissures were formed during the folding, faulting, and fracturing of the novaculite late in the Carboniferous period. The ores would be expected in those places where the novaculite has undergone much fracturing and close folding, as on and near faults and at the noses or ends of plunging anticlines. A number of such places where deposits occur are mentioned on pages 78–79. It is noteworthy that many cold springs and even the hot springs at Hot Springs, Ark., issue on the noses of plunging anticlines, showing that such places are especially favorable for the circulation of ground water.

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[1] Purdue, A. H., The slates of Arkansas, pp. 62–65, Arkansas Geol. Survey, 1909.

Hewett[1] has pointed out that some manganese deposits of Virginia and Maryland occur at or a few hundred feet below the Harrisburg (early Tertiary) peneplain, and he concludes that they were "formed during some stage of early Tertiary erosion." The deposits herein described occur at or several hundred feet below what are probably remnants of a Cretaceous peneplain, preserved in the even crests of the mountain ridges. They thus bear much the same relation to the Cretaceous peneplain of the region under discussion as the deposits described by Hewett bear to the early Tertiary peneplain of the Appalachian region. This similarity suggests that the ores here described were deposited about the beginning of the Cretaceous period, when the region had been reduced to a peneplain. Were this true, however, it would mean that they were deposited within a comparatively short time, but there is no evidence at hand to show that the deposition of the ores of the Caddo Gap and De Queen quadrangles could not have extended over a long period.

ANALYSES.

Analyses of psilomelane from North Mountain, in Montgomery County, and pyrolusite from Cossatot Mountain, in Polk County, are given on page 74. The following are analyses of manganese ores and manganiferous iron ores from the Caddo Gap and De Queen quadrangles:

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[1] Hewett, D. F., Some manganese mines in Virginia and Maryland: U. S. Geol. Survey Bull. 640, pp. 63–64, 1916.

Analyses of manganese and manganiferous iron ores from the Caddo Gap and De Queen quadrangles, Ark.

	1	2	3	4	5	6	7	8	9
Manganese (Mn)	60.28	58.36	55.80	51.54	48.65	48.34	40.51	27.68	26.20
Iron (Fe)	....	....	.50	....	2.03	....	25.53	35.39	16.83
Silica (SiO_2)	....	9.02	3.72	....	11.86	....	.80	1.88	29.00
Phosphorus (P)	.413	....	.038	.167	.308	.449	.767	.230	.343

	10	11	12	13	14	15	16	17
Manganese (Mn)	22.84	11.93	2.06	30.93	48.02	56.66	49.24	52.16
Iron (Fe)	....	22.26	50.38	9.21	5.56	.18	2.04	4.00
Silica (SiO_2)	.42	44.40	....	5.86	.52	.15	2.98	.24
Phosphorus (P)	.047	.576	1.450	.320	.310	Trace.	.380	.390
Manganese dioxide (MnO_2)	....	....	....	42.09	71.78	82.10	71.41	77.60

	18	19	20	21	22	23	24	25
Manganese (Mn)	42.75	59.55	25.99	30.95	16.45	23.96	60.54	43.52
Iron (Fe)	2.72	.74	10.75	12.80	5.11	7.45	....	6.72
Silica (SiO_2)	10.46	.52	5.21	6.20	17.16	25.00	8.30	[a] 5.17
Phosphorus (P)	.450	None.	.387	.461	.181	.264	.22	.35
Manganese dioxide (MnO_2)	62.75	90.52	....	....	....	....	....	([b])
Alumina (Al_2O_3)	....	....	8.44	10.04	8.62	12.55	....	4.80
Lime (CaO)	....	....	.04	.05	.04	.06	....	1.42
Magnesia (MgO)	....	....	.04	.05	.04	.06	....	Trace.
Sulphur (S)	....	....	.024	.029	.028	.041	....	.02
Moisture	....	....	16.04	....	31.35	....	....	....

[a] Silica and insoluble in HCl. [b] Oxidizing power equal to 64.60 per cent MnO_2.

Analyses 1 to 12 from Age of Steel, vol. 62, p. 9, Sept. 3, 1887; 13 to 19 from Penrose, R. A. F., jr., op. cit., p. 319; 20 to 23 furnished by Mississippi Valley Iron Co.; 24 furnished by Dierks Lumber & Coal Co. Analysts: 1, 4, 6, 12, Regis Chauvenet & Bro.; 2, 3, 5, 7–77, St. Louis Sampling & Testing Works; 13–19, R. N. Brackett; 24, Kansas City Testing Laboratory; 25, George Steiger.

1–12. Polk County, locality unspecified.
13. Line Mountain, Pike County.
14. Fancy Hill Mountain [W. R. Porter prospect], Montgomery County.
15. North Mountain [mine], Montgomery County.
16. McKinley Mountain, Polk County.
17. Tall Peak Mountain, Polk County.
18. Manganese Mountain, Polk County.
19. Cossatot Mountain, Polk County.
20–23. Still mine, Pike County. 20, One car, natural; 21, same, dry; 22, another car, natural; 23, same, dry.
24. Dierks Lumber & Coal Co.'s prospect, Montgomery County.
25. Composite sample from 39 localities in Pike, Polk, and Montgomery counties.

Analyses 1 to 12, inclusive, represent the composition of manganese and manganiferous iron ores from the land of the Arkansas Development Co. Analyses 15 and 19 were made on picked specimens and represent a better grade of ore than the average of the deposits from which they were taken.[1] Analyses 13, 14, 16, 17, and 18 were made on samples that were selected to represent as nearly as possible the average of the deposit.[2] Samples 20 to 23 were taken from two cars of ore containing 37 long tons, shipped by the Mississippi Valley Iron Co. from the Still Mine to its furnaces in St. Louis, Mo. Analysis 24 represents solid psilomelane collected by G. A. Joslin[1] from the smallest opening shown on figure 10 at the Dierks Lumber & Coal Co.'s prospect. Analysis 25 was made on a composite sample of specimens of manganese minerals collected by the writer from 39 localities, 20 grams of mineral from each locality being mixed to make the sample. The specimens consisted of wad, psilomelane, manganite, and bog manganese; they were selected from the parts of the deposit most free from iron oxide, clay, and fragments of novaculite. The localities from which specimens for the composite sample were collected are as follows:

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[1] Penrose, R. A. F., jr., op. cit., p. 318.
[2] Idem, pp. 318–320.

Nelson mine.
S. A. Hanna prospect.
Watkins-White prospects (pit farthest west).
Fagan mine.
Bear Mountain prospect.
Brushy Mountain prospects (first cut described).
Rattlesnake prospect.
Still mine.
Prospect No. 2.
Prospect No. 3.
Risner Mountain prospects (cut farthest west).
Janes prospects:
    Pit No. 1.
    Pit No. 3.
    Pit No. 4.
    Prospect No. 5.
    Pit No. 6.
    Pit No. 8.
    Pit farthest west.
Bud Hill prospect.
R. M. Cogburn prospect.
Robert Porter prospect.
Cady prospect.
W. R. Porter prospect.
North Mountain mine (Burns pit).
North Mountain mine (upper tunnel).
North Mountain mine (middle tunnel).
Slatington Mountain prospects (cut farthest east).
Dierks Lumber & Coal Co.'s prospect (three sets of specimens obtained from the two middle cuts).
Sugartree Mountain prospects (cut farthest northwest).
Tellus Davis prospect No. 1.
W. A. Davis prospect No. 1.
Eureka prospect.
Bluff Mountain prospect.

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[1] Personal communication.

Leader Mountain prospects:
- Claim No. 12.
- Ore picked up on surface on crest.
- North end of cut on claim No. 14.
- South end of cut on claim No. 14.
- Claim No. 5.

Grant prospect.

ECONOMIC POSSIBILITIES.

The possibilities of manganese mining in west-central Arkansas are ably discussed by Penrose,[1] from whom the following is quoted:

> The aggregate amount of manganese in the region is undoubtedly large, but it is distributed over an extensive area, and in almost all places it is hopelessly scattered through the rock in small nests and seams. If these nests and seams were in sufficient quantities the rock might be crushed and the ore concentrated by washing, but the pockets containing them are too small to permit the expense of machinery. It is a popular idea that the ore will increase in quantity at a depth, but there is absolutely no reason to expect this, as such deposits are just as likely and sometimes even more likely to become poorer at a depth than they are to improve.
>
> From the nature of the deposit it is to be expected that the ore at a depth is, at the very best, no more plentiful than in the surface outcrops of the so-called "lodes"—that is, that it exists as a series of pockets separated by greater or less distances of barren rock. With very few exceptions the pockets of ore seen on the surface can not be worked at a profit, and in the rare cases, where a small profit might be made, the amount would not be enough to pay for sinking through the barren rock that separates the pockets from each other. The intervening thickness of barren rock is much greater than the depth of any one pocket.

The quantity of manganese ore that can be mined at a profit from any one deposit is therefore small, which means that under normal conditions manganese mining will never become one of the chief industries in this region.

Ores from a number of manganese deposits, as shown by the chemical analyses on page 82, contain a sufficiently high percentage of manganese (40 per cent or more) and a sufficiently small percentage of silica (8 per cent or less) for the manufacture of ferromanganese, but most of the ores of which analyses are available exceed the phosphorus limit (0.20 per cent) for this purpose. The prices paid for medium-grade ores used in the metallurgic industries are relatively stable and generally range between $8 and $13.50 a ton,[2] being governed by the content of manganese, phosphorus, and silica. The price has, however, steadily increased since the outbreak of the war in Europe. Manganese ores sold in 1915 for $14.40 to $22.05 a ton,[3] and in 1916 the maximum price was $32.50.[1] This increase in price has accordingly increased the possibility of the economical recovery of the manganese ores of the area herein described, but some deposits that might now be worked at a profit will not pay to work after the price of ore again becomes normal, which will probably be within a year after the conclusion of peace.

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[1] Penrose, R. A. F., jr., Manganese—its uses, ores, and deposits: Arkansas Geol. Survey Ann. Rept. for 1890, vol. 1, p. 306, 1891.

[2] Harder, E. C., Manganese ores of Russia, India, Brazil, and Chile: Am. Inst. Min. Eng. Bull. 118, pp. 763–764, May, 1916.

[3] Hewett, D. F., U. S. Geol. Survey Mineral Resources, 1915, pt. 1, p. 39, 1916.

The wad and other low-grade oxides could be used for giving bricks a chocolate color. The pyrolusite, manganite, and psilomelane could be used to produce the spots of some varieties of speckled bricks and mixed with red-burning clay for brown bricks, and with buff-burning clay for gray bricks.

Some of the purer psilomelane and especially the manganite and pyrolusite could be used in chemical industries, in the manufacture of electric batteries, and for other purposes. Psilomelane is hard, however, and is less easily treated than manganite and pyrolusite. Ores required in the manufacture of dry batteries should contain less than 1 per cent of iron, less than 0.05 per cent of copper, nickel, and cobalt, and at least 80 per cent of manganese peroxide,[2] which is the form of the larger part of the manganese in pyrolusite, manganite, and psilomelane. The prices of ores suited for the above-mentioned purposes fluctuate greatly, ranging from $20 to $100 a ton.[3]

MINES AND PROSPECTS.

NELSON MINE.

The Nelson mine is on the northeast slope of a low crescent-shaped ridge that skirts the east end of Nelson Mountain, about 5 miles north-northeast of Glenwood. It was worked from August to December, 1915, by Chester Stevens and yielded 58 long tons of manganese ore, which was hauled in wagons to Glenwood and shipped to Birmingham, Ala., for use in the manufacture of ferromanganese. The workings consist of a northwestward-trending cut 25 feet wide, 50 feet long, 10 to 15 feet deep, and 100 feet above the wagon road at the base of the ridge and two northeastward-trending trenches on the slope above the cut. The strata exposed in the workings and on the crest of the low ridge are massive hard jointed white, somewhat porous novaculite, and belong to the upper division of the Arkansas novaculite, whose structure in this vicinity is that of an eastward-pitching anticline. The mine is on the east end or nose of this anticline. Although the beds in the workings are slightly wrinkled, their general dip is about 40° N. 40° E., and at the southeast end of the cut they are broken by a northeastward-trending fault by which the beds on the southeast side have been dropped a few feet.

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[1] Hewett, D. F., U. S. Geol. Survey Press Bulletin 306, January, 1917.

[2] Hewett, D. F., U. S. Geol. Survey Mineral Resources, 1915, pt. 1, p. 32, 1916.

[3] Harder, E. C., op. cit., p. 763.

The manganese ore consists of hard psilomelane, much of which shows botryoidal and stalactitic structure, and a meager quantity of crystalline manganite, some of which fills the centers of the psilomelane stalactites. It occurs as thin disconnected veins and pockets along joints and bedding planes. A 2-inch vein near the fault is the thickest one observed, but on the dumps there are pieces of ore that indicate the presence of veins at least several inches thick. In fact, veins a foot or so wide are said to have been found in the bottom of the cut, but they were obscured by débris at the time of the examination (April, 1916). Dendrites are common along the numerous cracks in the novaculite and are to be found on most pieces of rock from the cut.

The marketed ore was hand picked and is said to have carried 48.5 per cent of manganese and 1.75 per cent of iron. Ore in some of the discarded rock could be recovered by crushing and jigging, but the quantity is too small to make the installation of machinery for this purpose worth while.

The trenches above the cut are 2 feet wide and 1½ feet deep. The lower one is 40 feet long and shows no manganese oxide. The higher one, which is in line with the lower and is 90 feet long, shows brown iron oxide here and there but no manganese oxide. A few hundred pounds of the iron oxide has been thrown out, and some single pieces weigh about 100 pounds. The novaculite beds in the southwest end of the upper trench are near the base of the upper division of the Arkansas novaculite.

S. A. HANNA PROSPECT.

The prospect on the land belonging to S. A. Hanna is 1 mile south of the village of Caddo Gap, in a narrow gorge half a mile west of the hot springs that issue in the bed and edge of Caddo River. It consists of a northward-trending cut made in 1909 or 1910 on the south side of the gorge 300 feet above Caddo River. The cut is a few feet wide and 20 feet long, and at its south end is about 18 feet deep. The rock blasted out is hard white massive novaculite from a bed near the top of the lower division of the Arkansas novaculite, which here dips 50° N. 45° E. Thin veins of psilomelane and of a much smaller amount of brown iron oxide, both of which may occur in separate veins or together in the same vein or even in a small hand specimen, occupy some of the joints and bedding planes in the novaculite. The thickest vein, which is at the south end of the cut, is from 4 to 15 inches wide and dips 70° S. 50° E. Angular pieces of novaculite make up about one-fourth of this vein, and slickensides show on the hanging wall. Probably 1 ton of psilomelane has been removed from the cut, but no shipments have been made.

FRANK BRUNSON PROSPECT.

The prospect on land belonging to Frank Brunson is on the crest of a low ridge, near the west line of sec. 18, T. 5 S., R. 23 W., about 1 mile north of Rosboro. A little blasting has been done here in the uppermost division of the Arkansas novaculite. The small pit so formed shows irregular nodules and seams of brown iron oxide occurring along joints and bedding planes. A very small amount of manganese oxide is mixed with the iron oxide.

WATKINS-WHITE PROSPECTS.

Three openings were made in May, 1916, by H. L. Watkins and J. B. White on a low ridge 1 mile west of Glenwood. The one farthest east is a cut 8 feet wide, 15 feet long, and 8 feet deep, on the northeast slope of the ridge, about 200 feet above Caddo River. It is in the base of the upper division and the top of the middle division of the Arkansas novaculite, which here dip to the south at angles ranging from 30° to 40°. Seams of wad averaging less than an inch in width were found along bedding planes and joints through a 3-foot thickness of novaculite, but at one place a pocket of wad 3 feet long and 12 inches wide at the widest place was found. The wad is associated with psilomelane and manganite, and most of it is mixed with clay. Thin clay seams in the northeastern part of the cut contain brown iron oxide and a minute quantity of manganese oxide. Dendrites in lacelike forms are common.

A pit 12 feet long east and west, 6 feet deep, and 6 feet wide, is about 700 feet west of the cut just described, on the north slope of the ridge a few feet below its crest. It is in hard yellow massive novaculite in the upper division of the Arkansas novaculite. Oxides of manganese and iron were found in a few seams a fraction of an inch thick and in a pocket 4 feet long with a maximum thickness of 16 inches. Of these oxides massive steel-blue psilomelane, several hundred pounds of which has been placed on the dump, occurs in greatest amount. Some of it has botryoidal surfaces, and some occurs as small stalactite-like rods. Dendrites are abundant.

The third opening is a very small cut on the south slope of the ridge about 100 feet below its crest, southeast of the pit just described. It is in the upper division of the Arkansas novaculite, which is here a soft, porous buff-colored stone. Veins of psilomelane, usually less than an inch wide, ramify through the novaculite but are most numerous in a zone a foot wide striking across the bedding and dipping 90°. In some places brown iron oxide is associated with the psilomelane.

Commercial quantities of manganese ore have not been exposed in any of these three openings.

FIELDS PROSPECT.

The Fields prospect is a pit 6 feet wide, 8 feet long, and 3 to 4 feet deep, on the southwest slope of a low northwestward-trending ridge at the east end of Reynolds Mountain, in the SW. ¼ SE. ¼ sec. 32, T. 4 S., R. 24 W. It was made in June, 1916, by Messrs. Wright & Horn on land owned by R. C. Fields. The upper division of the Arkansas novaculite is exposed in the pit and forms the ridge at this locality. Pockets of brown iron oxide, some of which are several inches thick, were found along fissures in the broken novaculite, and in places they contain a small percentage of manganese.

REYNOLDS MOUNTAIN PROSPECTS.

A very small pit that in August, 1916, was being worked by Babbit & Co. is on the crest of Reynolds Mountain, in the SW. ¼ SW. ¼ sec. 6, T. 5 S., R. 24 W. Veins of psilomelane, manganite, and brown iron oxide attaining a thickness of several inches show in the massive novaculite in the pit and for a distance of 100 to 125 feet west of it. The iron oxide is the most abundant. Numerous needle-like stalactites of it, some 4 inches long, were found in a vug 2 feet wide, 8 inches high, and 3 or 4 feet long. The novaculite at this locality is in the basal division of the Arkansas novaculite and dips 40° or 50° S.

Some prospectors have recently broken off pieces of brown iron oxide from the face of a bluff 50 feet high on the south side of a small stream at the south base of Reynolds Mountain, in the eastern part of sec. 1, T. 5 S., R. 25 W. This oxide occurs as veins and pockets in the upper division of the Arkansas novaculite. One pocket is 4 feet long and 3 or 4 feet thick. No manganese oxide was seen here by the writer.

FAGAN MINE.

The Fagan mine is on the head of Cowlick Branch, in sec. 9, T. 5 S., R. 25 W. The workings, which are near the level of the branch where it flows through a water gap, consist of a north-south, badly caved cut 60 feet long on the west side of the branch and a pit a few feet east of the branch. The cut was made several years ago. Some work was done in the pit in 1916 by Will Fagan and some was done later in the same year by Edgar & Co., but work by this company was discontinued on the day of the writer's examination (Aug. 8, 1916).

The cut is in vertical beds near the base of the Arkansas novaculite, but it has caved so much that no ore is visible. The pit is 12 feet square and 14 feet deep, and the bottom is 4 or 5 feet below the bed of the branch. The novaculite into which it has been sunk is only about 20 feet south of the contact of the Arkansas novaculite with the Missouri Mountain slate, which is exposed in the branch to the north, and the rock is so open from shattering that frequent vigorous bailing was necessary to keep the water out. A northeastward-trending zone of this shattered novaculite 10 feet wide and containing in places thin veins of crystalline manganite has been uncovered for 30 feet in the northwest half of the pit and in a trench leading from it. Associated with the manganite is a small quantity of stalactitic and botryoidal brown iron oxide. The manganite makes up only a small percentage of the rock mass, and to recover it would require crushing and jigging, which probably would not be profitable.

BEAR MOUNTAIN PROSPECT.

A cut made on the Rose placer-mining claim in May, 1916, by the Mississippi Valley Iron Co., is on the west end of Bear Mountain, 9 miles in a straight line west of Glenwood, and is 25 feet above Self Creek, which here flows southward through a gap at the west end of the mountain. The cut is 14 feet square and on the east side shows a 10-foot vertical face of massive shattered novaculite that has been bent into an anticline whose axis trends eastward. Slickensides were observed in places. Three lenses of manganese oxide, the largest 6 inches wide, lie along bedding planes (fig. 5), and at two places manganese and iron oxides occur in thin films ramifying through the novaculite and penetrate the novaculite away from the films. A few hundred pounds of manganese oxide consisting of psilomelane banded with a very small amount of manganite has been piled on the dump.

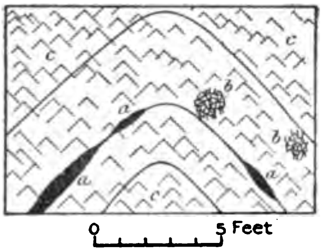

FIGURE 5.—Section of east face of Bear Mountain prospect, Pike County, Ark., showing veins (*a*) of manganese ore along the bedding planes and a network of films (*b*) of iron and manganese oxides at the crest of an anticline in the novaculite (*c*).

BRUSHY MOUNTAIN PROSPECTS.

Four cuts on Brushy Mountain, in the S. ½ SW. ¼ SW. ¼ sec. 5, T. 5 S., R. 25 W., were made in May, 1916, by the Mississippi Valley Iron Co. The principal one is 45 feet long, from 7 to 14 feet wide, and 8 feet deep at the deepest place and is on the south slope of the mountain 40 feet above Self Creek. It is in massive novaculite dipping 25° or 30° S., on the south side of a small westward-plunging anticline. A bed of conglomerate overlying the massive lower division of the Arkansas novaculite is exposed at the north end of the cut. A zone of novaculite breccia, from 1 foot to 3½ feet thick is exposed on the west side of the cut and on part of the east side. The novaculite fragments are cemented together by a much less quantity of hard steel-blue psilomelane, which in places occurs in stalactite-like rods and in places has botryoidal surfaces. Some pockets of psilomelane are found in this zone, but the largest ones are only a few inches wide, and few exceed a foot in length. Below this zone there are coatings of psilomelane along some of the bedding planes and stains of it along some cracks in the novaculite. Dendrites are common. Several hundred pounds of psilomelane free of rock has been placed on the dump.

A second cut 18 feet long from east to west, 2 to 3 feet deep, and 2 to 4 feet wide is on the north bank of Self Creek 75 feet southwest of the cut just described. It is in massive crushed novaculite dipping to the southwest and west, on the southwest slope of the small anticline mentioned in the preceding paragraph. A small quantity of psilomelane cements together fragments of novaculite or occurs as veins an inch or less thick.

A third cut, 10 feet wide, 15 feet long, and 5 feet deep on the upper side is 150 west of the first one described and at about the same height above Self Creek as that cut. The highest bed exposed in the cut is a flat-lying conglomerate 3 feet thick, which is the same bed as the one exposed at the north end of the first-described cut. Brown iron oxide is found as veins along joints in this conglomerate and as cementing material in a bed of breccia 2 to 3 feet thick below the conglomerate. A minute quantity of manganese oxide is mixed with the iron oxide, and some dendrites are present. The prospect is on the nose or west end of the small westward-plunging anticline.

The fourth cut is 20 feet long from north to south, 6 feet wide, and 1 to 2 feet deep and is 50 or 60 feet northwest of the third one. It is northwest of the westward-plunging anticline in this vicinity and merely lays bare the upper surface of the above-mentioned conglomerate, which dips the same as the slope—that is, 25° S. No manganese oxide was found here.

It is obvious from the above descriptions of the four openings that manganese oxide occurs only in small quantity at this locality and will probably not be found to increase in quantity with increasing depth.

W. T. WHITE PROSPECT.

A pit was made in June, 1916, by W. T. White well up on the south slope of Warm Spring Mountain, in the eastern part of sec. 11, T. 5 S., R. 26 W. It is L shaped, with each arm 8 feet long, and is 8 feet deep in the deepest part. The novaculite exposed near by dips 55° N. 10° W. and is near the top of the lower division of the Arkansas novaculite. A mixture of brown and red oxides of iron and of novaculite fragments embedded in clay is exposed in the pit and for 10 feet west of it. At only one place in the pit do these oxides look as if they might contain a small percentage of manganese, and at another place they contain a minute quantity of brown altered dufrenite. Although a few hundred pounds of iron oxide has been removed from the pit, it does not occur in sufficient quantity to be mined with profit.

N. F. WHITE PROSPECT.

Three very small openings on the mountain side 400 or 500 feet southwest of the W. T. White pit were made in June, 1916, by N. F. White, in the massive novaculite in the upper division of the Arkansas novaculite, whose beds here dip 90°. A few seams of psilomelane and manganite an inch or less thick occur along bedding planes and joints, and some manganese oxide penetrates the novaculite for a fraction of an inch.

RATTLESNAKE PROSPECT.

The Rattlesnake prospect is on Redland Mountain, on the west side of sec. 9, T. 5 S., R. 26 W. It consists of a cut 85 feet long, from 2 to 6 feet deep, and extending from north to south across the crest. Massive novaculite dipping 60° S. and belonging in the lower division of the Arkansas novaculite is exposed in the south end of the cut for a distance of 35 feet. A few widely separated veins of steel-blue psilomelane and brown iron oxide, which occur together, even in the same part of a vein, were found in the novaculite. These minerals penetrate the novaculite to a depth of a fraction of an inch. The largest vein, which is from 2 to 9 inches wide, occupies a joint dipping to the north and contains some pieces of novaculite.

Green shale and thin-bedded flint were penetrated for a distance of 30 feet just north of the massive novaculite, from which they are separated by a foot of manganiferous and ferruginous slate. The rest of the cut is in massive novaculite that shows no ore.

The work at this locality was done in May, 1916, by the Mississippi Valley Iron Co.

STILL MINE.

The Still mine is on the southwest slope of Hogpen Mountain, a peak in the northwest corner of T. 5 S., R. 26 W. It receives its name from the ruins of a "moonshine" still on Hogpen Branch, which flows southward along the west base of the mountain. Work was being done here at the time of the examination (Aug. 6, 1916) by the Mississippi Valley Iron Co. The workings consist of a tunnel and a T-shaped cut 75 feet above Hogpen Branch. (See fig. 6.)

The north-south part of the cut is in thin-bedded vertical novaculite, between whose layers are seams of clay. These beds are at the base of the middle division of the Arkansas novaculite and contain a very small quantity of brown iron oxide and a short vein of ferruginous manganese. The east-west part of the cut, about 25 feet deep, and the tunnel are in massive beds of hard, shattered novaculite, striking east and dipping almost 90°. These beds are at the top of the lower division of the Arkansas novaculite and show irregular veins and pockets of ore mixed with clay. Some of the veins and pockets are as much as 6 inches thick and a few 18 inches, but they make up only a small portion of the rock mass. Most of the ore is wad and is free of rock, but some is psilomelane and a little is manganite, which is usually disseminated through the psilomelane. Dendrites are common along cracks in the novaculite.

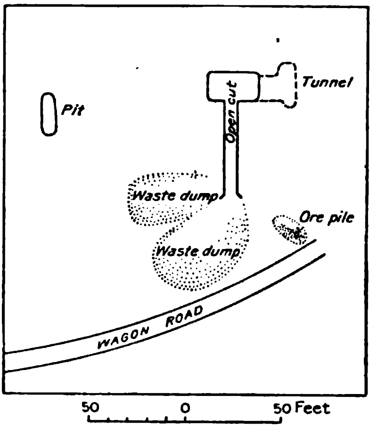

FIGURE 6.—Plan of Still mine on Hogpen Mountain, Pike County, Ark.

A pit to the west is 50 feet above Hogpen Branch and was partly filled with water at the time of visit. The south end is in thin-bedded novaculite, and the north end in massive novaculite, which belong to the middle and lower divisions of the Arkansas novaculite, respectively. The beds in the two divisions strike east, dip 90°, and are separated by a 3-foot bed of conglomerate composed of round and subangular pebbles of novaculite in a sandy and dense flinty matrix. Films of iron and manganese oxides occur through the novaculite, but no veins are visible.

About 37 long tons of ore as taken from the mine without washing or other preparation was hauled to Glenwood, 20 miles away, and then shipped to the company's iron furnaces in St. Louis, where it was used to raise the manganese in pig iron above 1 per cent. A fews tons of ore, consisting mainly of wad mixed with much clay, still remains on the ore pile. Better transportation over a proposed logging spur to be built within 1¼ miles of the mine was expected within a few months after the writer's visit, but mining at this place has since been discontinued, the reason given being that the results were disappointing both as to the quality and quantity of the ore.[1] Analyses of the ore shipped, given on page 82, show that the phosphorus content is too high and the manganese content too low for use in the manufacture of ferromanganese.

PROSPECT NO. 3.

Prospect No. 3 of the Mississippi Valley Iron Co. is on the south slope of Hogpen Mountain, about 750 feet east of the Still mine and 200 feet higher on the mountain. Work was begun here August 1, 1916, and at the time of examination, five days later, a cut 15 feet long, 3 to 4 feet deep, and 5 to 6 feet wide had been made. Most of the cut was in red clay, but the north end showed some massive novaculite that was penetrated by thin films of manganese oxide. This novaculite, like the massive novaculite in the Still mine, is at the top of the lower division of the Arkansas novaculite. Psilomelane associated with a minor amount of wad and some brown iron oxide was found in red clay for a north-south distance of 7 feet. One boulder, weighing 300 or 400 pounds and said to have been exposed on the surface, thus furnishing a reason for making the cut here, was rolled down the mountain and shipped with the ore from the Still mine. If further work should prove that this manganese-bearing clay maintains a width of 7 feet at depth and for some distance on the surface, this would be a promising prospect.

PROSPECT NO. 2.

Prospect No. 2 of the Mississippi Valley Iron Co. consists of a cut on the south slope of Hogpen Mountain about 120 feet east of prospect No. 3. The work was done in June, 1916. The cut extends 60 feet N. 20° W. into the mountain, and is 25 feet deep at its north end. Its south end is in the middle part of the Arkansas novaculite, and the north end in the lower part, both of which dip 80° or 85° S. The middle part of the formation consists of novaculite, usually in thin layers interbedded with clay. The lower part, which is exposed for 24 feet at the north end and which is separated from the middle part by a conglomerate, consists of nodules, layers, and lenses of jointed novaculite interbedded with much clay. Small pockets and veins of wad mixed with clay ramify through the whole bed, but they constitute a very small percentage of the bulk of the rock, and none of them exceed a few inches in thickness. A few hundred pounds of wad has been placed on the dump.

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[1] Letter dated Dec. 6, 1916, from the Mississippi Valley Iron Co.

RISNER MOUNTAIN PROSPECTS.

Risner Mountain is a short ridge west of Hogpen Mountain, from which it is separated by the gorge through which Hogpen Branch flows. Two north-south cuts were made on it in July, 1916, by the Mississippi Valley Iron Co. One of these, 34 feet long and 4 feet deep, is on the southeast slope about 300 feet above Hogpen Branch, a quarter of a mile southwest of the Still mine. The south end has been blasted in massive novaculite at the top of the Arkansas novaculite, and the north end in thin-bedded novaculite interbedded with clay. Iron oxide in thin films is the only mineral observed in the cut, but several pounds of brown iron oxide and a few pieces of novaculite, to which a little psilomelane adheres, were seen on the dump. The iron and manganese oxides penetrate the novaculite to a depth of half an inch along some of the cracks.

The other cut, known as prospect No. 4, is on the south slope of the mountain, northwest of the one just described and about 100 feet higher. It is 42 feet long and at its north end is 20 or 25 feet deep. Its south end is in conglomerate and thin-bedded novaculite. This conglomerate is the same bed as that found in the pit near the Still mine and in prospect No. 2, on Hogpen Mountain. The rest of the cut is in massive jointed novaculite dipping 65° S., some of which occurs as nodules and lenses. A few veins of wad, brown iron oxide, and ferruginous manganese oxide mixed with much clay were found near the south end of the cut north of the conglomerate. They are thickest through a north-south distance of 7 feet, but even there they are only a few inches thick and constitute only a small part of the rock mass. Farther north are thinner veins of manganese oxide associated with red and yellow clay along bedding planes and joints. Dendrites are abundant along cracks in the novaculite. Only a small quantity of manganese oxide was found in the cut, and all was thrown away with the waste except 100 or 200 pounds that was placed in a pile. In this pile are pieces of iron oxide and psilomelane containing manganite. The manganese minerals in this cut are at the same horizon as in the Still mine and in prospects Nos. 2 and 3, namely, at the top of the massive novaculite that makes up the lower division of the Arkansas novaculite.

R. M. COGBURN PROSPECT.

The prospect of R. M. Cogburn is on the crest of Brooks Mountain, in the eastern part of sec. 3, T. 5 S., R. 26 W. The only work done here has been the overturning of a few boulders of novaculite by means of crowbars. Veins and pockets of psilomelane a few inches thick show on these boulders.

A little prospecting is said to have been done at other places on Brooks Mountain, but the writer did not examine the openings.

BUD HILL PROSPECT.

An exposure of "bog ore" in which a little digging has been done is on Bud Hill's land, in the north-south wagon road half a mile southwest of Fancy Hill post office. The deposit crops out for about 150 feet along the road and overlies thin-bedded novaculite in the middle division of the Arkansas novaculite, some pieces of which are embedded in it. The deposit probably does not exceed a few feet in thickness. Iron oxide is being deposited by two small springs that issue from the "bog ore," which is itself probably a spring deposit.

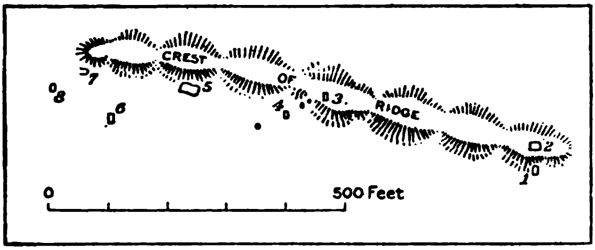

FIGURE 7.—Sketch map showing the location of most of the Janes prospects, Montgomery County, Ark. Numbers refer to openings described in the text.

JANES PROSPECTS.

A number of openings were made from February to June, 1916, by M. A. Janes on a low ridge in the eastern part of sec. 19, T. 5 S., R. 25 W. (See fig. 7.) The upper division of the Arkansas novaculite, here about 50 feet thick, forms the crest of the ridge. It consists of massive jointed novaculite, which strikes parallel with the direction of the ridge and dips at angles exceeding 65°. The openings are described and numbered in the order in which they were examined, beginning at the east.

A 5½-foot bed of novaculite in the north end of pit No. 1, which is 16 feet long, 9 to 10 feet wide, and 2 to 6 feet deep, contains irregular veins of manganese oxide that in places reach a maximum thickness of 12 inches, but if they were all put together their average aggregate thickness across the pit would not exceed 10 inches. Two thin veins, one of which is 3 inches thick, occur farther south. Dendrites and other manganese stains along joints are common. The other manganese minerals are wad, manganite, and psilomelane, the last two predominating.

Pit No. 2, 12 feet wide, 13 feet long, and 2 to 3 feet deep, reveals two veins of mixed manganese and iron oxides parallel with the bedding. The northern vein is from 12 to 18 inches wide; the southern one is thinner. About 2 tons of these oxides has been removed from the pit and placed on the dump.

Pit No. 3, 10 feet long, 3 to 4 feet wide, and 2 to 3½ feet deep, shows a small quantity of psilomelane which on the east side occurs in a 19-inch vein of clay between layers of novaculite and which on the west side occurs as two veins, each 2 inches wide, and as fragments in surface clay. The psilomelane is comparatively free of iron oxide. About half a ton of it has been removed from the pit.

Pit No. 4, 6 feet long, 4 feet wide, and 3 feet deep, shows veins and pockets of psilomelane 1 foot in maximum width, in which there are pieces of novaculite. The psilomelane placed on the dump weighs about 500 pounds. One piece alone weighs about 150 pounds. A very small pit 50 feet southwest of pit No. 4 has yielded 100 pounds of psilomelane and manganite, and two small ones about midway between pits Nos. 3 and 4 have yielded 25 or 30 pounds of psilomelane.

A group of adjoining pits and cuts (prospect No. 5), all within an area 30 feet long from east to west and 14 feet wide, reveals three manganese veins. One of these is from 3 to 6 inches wide; another, which is exposed for a distance of 6 feet, attains a maximum width of 15 inches; and the third, which is exposed for a distance of 16 feet, is 20 to 22 inches wide and at the east end of the exposure contains some fragments of novaculite. The three veins are composed almost entirely of psilomelane; the rest is brown iron oxide and manganite. Probably 3 tons of these oxides lie on the dump.

The largest visible vein of manganese in pit No. 6, which is 12 feet long, 6 feet wide, and 2 to 5 feet deep, is 2 inches wide, but several hundred pounds of psilomelane lying on the dump is said to have been removed from surface clay. A pocket of manganese oxide 8 inches wide is exposed 12 to 15 feet northeast of pit No. 6, and a 14-inch vein of brown iron oxide is exposed about 20 feet west of pit No. 5.

A few blasts at prospect No. 7 have been made on an outcrop of brown iron oxide mixed with some psilomelane. These minerals occur in a vein that ranges from 3 inches to over 3 feet in width and is exposed for an east-west distance of 10 feet.

Pit No. 8, 6 feet long, 2½ feet wide, and 1 to 3 feet deep, shows a 20-inch vein of soft and hard manganese oxides containing some red clay and a few fragments of novaculite. A boulder of solid psilomelane that protruded above the surface 20 feet west of this pit has been dug up. It weighs about 175 pounds.

Parts of the deposit just described might possibly be worked on a small scale.

Another pit made in July, 1916, by Mr. Janes is well up the south slope of Caddo Mountain, near the west line of sec. 19, T. 5 S., R.

25 W. It is 8 feet long, 2 to 3 feet wide, and at the north end 3 feet deep. It is in massive novaculite at the very top of the lower division of the Arkansas novaculite, which here dips 85° N. Small pieces of psilomelane were found in surface clay, and outcrops of this mineral were observed on protruding ledges of novaculite for a distance of fully 200 feet west of the pit.

CADDO MOUNTAIN PROSPECT.

A cut 15 feet long, 4 feet wide, and 1 to 3 feet deep was made a number of years ago about 450 feet east of the forest ranger's tower that is on the highest point of Caddo Mountain, northeast of Fancy Hill post office. It is just south of the trail leading east along the crest of the mountain. Some of the novaculite boulders that were thrown out of the cut are brecciated and the fragments are cemented together with narrow veins of psilomelane.

A number of openings are said to have been made along the crest west of the ranger's tower, but they were not visited.

ROBERT PORTER PROSPECT.

The Robert Porter prospect is on the north slope near the crest of a hill at the north base of Fancy Hill Mountain, in the northern part of sec. 28, T. 4 S., R. 26 W., and is about 200 feet above South Fork. The workings consist of two cuts made in the spring and summer of 1916. The lower cut is 9 feet long from north to south, 3 to 4 feet wide, and 1 to 1½ feet deep, and the other, which is on the slope just above it, is 20 feet long, 3 to 7 feet wide, and 1 to 4 feet deep. The massive beds of the upper division of the Arkansas novaculite form the crest of this hill and dip 60° N.

The manganese deposit revealed in the cuts and in exposures on either side consists largely of boulders of iron and manganese oxides lying on the surface. These boulders appear to have been once a part of a surficial layer from a few inches to 18 inches thick which was probably deposited from an extinct spring that issued at this locality. They are found within a north-south distance of 30 feet, and some were seen along the slope for a distance of 100 feet west of the cuts, but their size decreases toward the west.

A 4-foot vein of ore occurs in the novaculite at one place in the upper cut, and much thinner veins were seen in near-by outcrops of the novaculite.

The deposit is well described, as follows, by Penrose:[1]

> The manganese ore is a hard, black variety, and the iron is in the form of a bright vitreous brown ore, often having a honeycombed structure. The two are intimately mixed together, the iron being much the more plentiful;

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[1] Penrose, R. A. F., jr., op. cit., pp. 349–350.

and sometimes nodules of manganese, from a fraction of an inch to 1 inch in diameter, are cemented in a matrix of iron ore. Sometimes the ores are comparatively free from any admixture of rock, and at other times they form the cement of a novaculite breccia. * * *

The deposit represents a pocket of ore much larger than is usually seen in the gray novaculite, but, as shown by the accompanying analysis, it is of poor quality for use in the manufacture of spiegeleisen and ferromanganese on account of its high percentage of phosphorus; and its association with iron renders it undesirable for many chemical purposes. Its high percentage of peroxide of manganese, however, would for some purposes counterbalance the latter disadvantage.

Analysis of manganese ore from Fancy Hill Mountain, Montgomery County.

[R. N. Brackett, analyst.]

Manganese	48.02
Iron	5.55
Silica	.52
Phosphorus	.31

Manganese peroxide, 71.73.

CADY PROSPECT.

The Cady prospect is about 150 feet above South Fork, on the north slope of a low hill, about a quarter of a mile east of the Robert Porter prospect. It consists of two cuts made in the spring and summer of 1916. The hill is formed by the massive beds of the upper division of the Arkansas novaculite, which here dips 60° N. The larger cut, 11 feet long, 8 feet wide, and 5 feet deep on the south side, contains a pocket of clay that, although partly removed, appears to be 5 feet long, 3½ feet wide, and 3 feet thick. Botryoidal and stalactitic psilomelane and a smaller quantity of manganite are embedded in the clay. Probably half a ton of these manganese minerals has been taken out and placed on the dump.

A smaller cut, 3 feet long, 2½ feet wide, and 1½ feet deep, is 25 feet west of the one just described. It is in surface clay and rock débris and has yielded 500 pounds or more of psilomelane, one piece of which weighs nearly 150 pounds.

W. R. PORTER PROSPECT.

The prospect of W. R. Porter is on the south slope of Bald Mountain, about 400 feet above its base, in sec. 17, T. 4 S., R. 26 W. It consists of a small cut made in June, 1916, in the top of the lower division of the Arkansas novaculite, which here dips 50° S. Stains, thin veins, and pockets of manganese and iron oxides were found in the novaculite and in clay, and a few veins show on large boulders of novaculite, of which some are near their parent ledge, but others have rolled down the mountain side. A vein of hard, compact psilomelane is exposed on a ledge of novaculite 125 feet west of the cut. The vein in the lower part of the exposure, where it passes beneath surface material, is 16 inches thick, but 4 feet away in the upper part of the exposure it is only a fraction of an inch thick.

NORTH MOUNTAIN MINE.

North Mountain is a local name given to a broken novaculite ridge in the northern part of T. 4 S., R. 27 W., near the headwaters of Little Missouri River. It is a part of Statehouse Mountain, shown on the Caddo Gap topographic map.

A manganese deposit on the south slope of North Mountain is being extensively explored by Edgar & Co., who have erected an air-compressing plant at the mouth of the lower tunnel and a sawmill at the base of the mountain, and have been working here since early in May, 1916. (See fig. 8.) The first opening at this locality consisted of a pit blasted out almost 30 years ago by a Mr. Burns, who shipped 4 tons of ore.

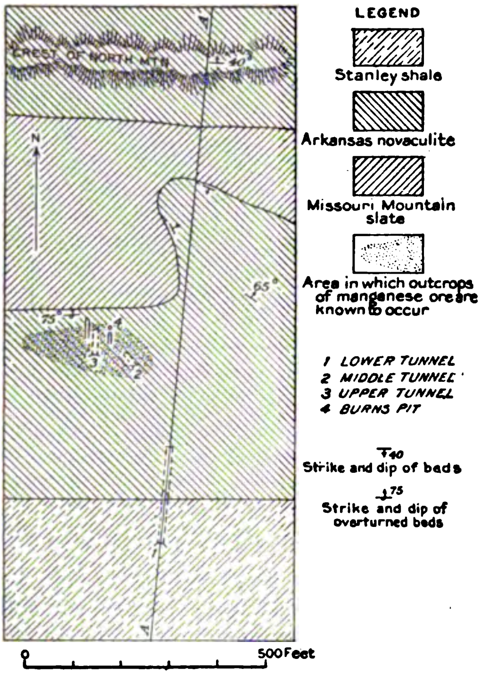

FIGURE 8.—Sketch geologic map showing workings on south slope of North Mountain, Montgomery County, Ark.

The deposit occurs in the lower division of the Arkansas novaculite, and although it is on the south side of a closely compressed easterly anticline, the structure is complicated by a minor anticline just northeast of the deposit. (See figs. 8 and 9.) The crest of the mountain north of the workings is 780 feet above the wagon road at the south base of the mountain. The lower tunnel, which is 10 feet wide and 7 feet high, is 250 feet above this road and was about 200 feet long at the time of the writer's examination (Aug. 4, 1916). It passes through the base of the Stanley shale and the upper division of the Arkansas novaculite and at a distance of 200 feet back into the mountain is in the middle division of the formation, which consists of hard layers of novaculite and black shale. This tunnel is being driven into the mountain to determine the downward extent of the exposed manganese deposit. The only manganese found before the examination consists of thin films in the upper division of the novaculite, but a recent communication[1] states that an 8-foot vein of solid manganese was found about 615 feet from the mouth of the tunnel. Native copper is also reported to have been found at places in this tunnel. Specimens sent to the writer by R. Lowery, of Albert, Ark., consist of broken pieces of novaculite and quartz cemented together by films of chalcedony in which are small particles of native copper. The chalcedony is stained bluish green by a minute quantity of chrysocolla, a copper silicate combined with some water.

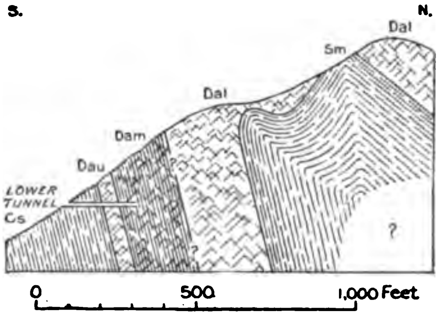

FIGURE 9.—Section along line A–A, figure 8, on south slope of North Mountain, Montgomery County, Ark. Cs, Stanley shale; Dau, upper division of Arkansas novaculite; Dam, middle division of Arkansas novaculite; Dal, lower division of Arkansas novaculite; Sm, Missouri Mountain slate.

The middle tunnel is 166 feet above the lower, or 416 feet above the base of the mountain, and at the time of visit was 35 feet long. The novaculite penetrated by it is massive and very hard, is much shattered, shows some slickensides, and belongs to the lower division of the formation. A vein of manganese oxide 2 to 6 inches wide shows in a joint on the northeast side of the tunnel and about halfway back. Another vein 4 to 15 inches wide is revealed on the southwest side near the portal but does not appear on the northeast side. Besides these two veins some thin films and veins an inch or so thick were observed.

The upper tunnel is 50 feet above the middle tunnel, or 466 feet above the base of the mountain and was 50 feet long at the time of visit. It penetrates massive shattered, very hard novaculite like that in the middle tunnel. Manganese ore mixed with some clay occupies narrow fissures and spaces between fragments of novaculite through a distance of 14 feet at the face of the tunnel. Practically all the ore on the dump contains fragments of novaculite, but pieces of solid ore weighing several pounds were seen.

A cut that is 45 feet long and 10 feet west of the upper tunnel reveals a zone of breccia ore which is apparently the same as that found in the back of this tunnel. The zone in the vertical exposure of 5 feet on the west side of the cut is 2½ feet wide at the top and 3¾ feet wide at the bottom; it is also present on the east side, but the dimensions are different. A lens of breccia ore 10 feet long and 8 inches thick was found at another place. The manganese ore in this cut cements novaculite fragments together, but it does not fill the entire space between the fragments. The north end of this cut is 20 feet south of the contact of the Arkansas novaculite with the Missouri Mountain slate, and the ore farthest north in the cut is 35 feet south of this contact.

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[1] Letter dated Dec. 6, 1916, from Chester Stevens, formerly of Edgar & Co.

A shallow cut 2 to 5 feet deep and a small pit at its north end are 20 feet east of the upper tunnel and show manganese ore for a north-south distance of 30 feet. The deposit is an eastward continuation of the same zone as that found in the upper tunnel and in the cut to the west. The pit is the one that was blasted out almost 30 years ago by Mr. Burns. It was visited by Penrose,[1] who describes the ore as follows:

> The ore is a hard glossy black variety and usually forms the cement of a breccia of angular novaculite fragments from a fraction of an inch to 4 or 5 feet in diameter. The ore forms from an eighth to less than a quarter of the mass. In spots, however, there are comparatively pure bodies of it, and a horizontal pocket of such ore about 2 feet wide runs across the face of the pit. It contains no rock, but a small lenticular layer of clay a few inches thick is included in it. Such masses of pure ore are rare and of limited extent. Figure 10 represents the face of the opening and illustrates the occurrence of the ore.
>
> The mass of novaculite in the center is surrounded by smaller pieces cemented by manganese ore and represents simply an exceptionally large component fragment of the breccia. It is noticeable that the angles of almost any two adjacent fragments of novaculite would fit into each other if the separating layer of manganese was removed, showing that the breccia has been formed by the breaking of the rock in place and not by an indiscriminate mixing of rock fragments.

The ore-bearing breccia is largely obscured by loose material, but it was not found in rock exposures east of the pit and cut east of the upper tunnel or west of the cut west of this tunnel. However, seams of manganese oxide a few inches thick were observed in outcrops of massive novaculite as far as 50 feet southwest and 150 feet west of the mouth of the upper tunnel and 20 feet east of the mouth of the middle tunnel.

The ore consists of hard steel-blue psilomelane showing in places a banded structure and in places a botryoidal surface. It is associated with a small quantity of wad, and some of it contains minute quantities of manganite. Some of the psilomelane occurs in layers alternating with wad. Analyses of psilomelane from this locality are given on pages 74 and 82.

The deposit just described represents a local accumulation of manganese in the ordinarily compact novaculite, after open spaces had been formed in it by the processes of brecciation and folding. The proximity of the deposit to the nose of the small anticline near by suggests that the brecciation was caused by crushing forces accompanying the formation of the anticline. The reported discovery of an 8-foot vein of solid manganese ore in the lower tunnel 216 feet below the upper tunnel, which penetrates the exposed ore body, may mean that the exposed ore body continues down to the lower tunnel, but the discovery does not necessarily prove this to be so. The 8-foot vein may in fact turn out to be merely a pocket separated from the exposed ore body by an intervening mass of novaculite.

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[1] Penrose, R. A. F., jr., op. cit., p. 352.

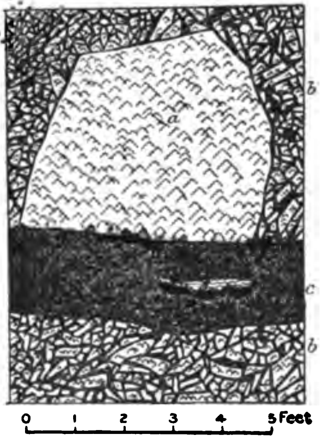

FIGURE 10.—Section in a pit on North Mountain, Montgomery County, Ark., showing a manganiferous breccia in the Arkansas novaculite. (After Penrose.) *a*, Novaculite fragment; *b*, breccia of novaculite fragments in a cement of manganese ore; *c*, pocket of manganese ore; *d*, clay.

The writer agrees with the following statement made by Penrose:[1] "The deposit is limited. Some manganese could doubtless be taken out at a profit, but the deposit would soon run into ore in quantities too small to work."

The ore at this locality is so intimately mixed with fragments of novaculite and adheres so tightly to the novaculite that only a small proportion of the mined ore could be hand picked; the rest would require treatment in a concentrating plant.

CROOKED CREEK.

Penrose[2] describes as follows some pits near Crooked Creek:

> Crooked Creek runs west through the northern tier of sections of 4 S., 27 W., and then turns abruptly to the southeast, flowing thence into the Little Missouri River in the same township. It forms one of the main forks of the Little Missouri River in this region of the headwaters of that stream, and its valley is bordered by novaculite ridges. Several small pits have been sunk on the ridges on the outcrop of the manganese and iron bearing stratum.
>
> On the top of the more southerly of the two novaculite ridges immediately south of the creek, probably in sec. 10, a small pit has been sunk on the gray novaculite, showing a hard black manganese ore, in seams rarely over a quarter of an inch in thickness and generally thinner, penetrating the rock in all directions. The ore is frequently stained with iron, and often small masses of manganese ore inclose kernels of brown hematite.
>
> About a mile east of this exposure, on the south slope of the same mountain, in the gray novaculite and near its contact with the shale, a small prospect pit has been sunk on iron ore. The ore is found in the rock in small seams and

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[1] Penrose, R. A. F., jr., op. cit., p. 353.

[2] Idem, p. 351.

pockets from 1 to 4 inches in thickness. It is frequently fibrous, porous, or stalactitic and very often has a brilliantly iridescent surface showing glossy green, blue, and pink colors. It decomposes on a weathered surface into a brown earthy ore. The ore on Crooked Creek has nowhere been seen in workable quantities.

SLATINGTON MOUNTAIN PROSPECTS.

Some manganese deposits on the south slope of Slatington Mountain, in the northwestern part of T. 4 S., R. 27 W., were prospected in June, 1916, by Edgar & Co. This mountain is one of the group known as the Missouri Mountains, and the prospecting was done about a mile north of Round Mountain.

A north-south cut 2 to 3 feet deep, several feet wide, and 45 feet long, was made along the bed and side of a southward-flowing branch to explore a deposit of ferruginous bog manganese which cements together fragments of novaculite and shale. Where the deposit is revealed in the cut—for about 25 feet along the east side of the branch—it is 6 feet wide, and at one place where the cut went through the deposit it is 20 inches thick and underlain by interbedded shale and novaculite. How far the deposit extends west of the stream is not known, but it was seen at places for a distance of 150 feet downstream and about the same distance upstream. The branch water running over this "bog ore" is now depositing iron oxide.

On the south slope of the mountain, about 250 feet north of the cut just described, is a pit 6 feet wide, 7 feet long, and 3 feet deep. A surficial deposit of iron oxide containing a small quantity of manganese is exposed in the pit and for several feet on each side, and one outcrop of the deposit was seen 85 feet east of the pit. The deposit is 3 feet thick at the pit and overlies shale and thin-bedded novaculite.

A second cut in this vicinity is about 300 feet east of the one in the branch, on a slope about 100 feet above the branch. It is 5 to 8 feet wide and 3 to 6 feet deep, and extends 25 feet parallel with the strike of the novaculite, N. 70° E. The novaculite, which has been blasted out to make the cut, is massive, light colored, and hard, is in the upper division of the formation, and dips 35° S. 20° E. Two parallel veins of iron and manganese oxides 2 feet apart were found here between the beds of novaculite. The upper vein ranges from a fraction of an inch to 4½ inches in thickness and consists of brown iron oxide, ferruginous manganese oxide, manganese oxide, and fragments of novaculite. The lower vein is from a feather edge to 12 inches thick and branches upward into two veins, each of which is an inch or two thick. It is composed mainly of brown iron oxide, with which a little manganese oxide is mixed. The manganese minerals in this cut are hard steel-blue massive psilomelane and manganite, the latter in small quantity.

MISSOURI MOUNTAIN PROSPECT.

A shallow north-south cut 13 feet long and 3 to 5 feet wide was blasted out on the north slope near the summit of Missouri Mountain, in sec. 31, T. 3 S., R. 27 W., in the spring of 1916, by J. T. Smith, who has since sold his claim to Edgar & Co. The rock blasted out is hard, massive, crushed novaculite belonging to the lower division of the Arkansas novaculite. It contains some irregular veins and pockets of brown iron oxide and a little psilomelane along joints; the largest vein is 3½ inches wide. These two minerals occur in separate veins, in the same part of a single vein, or in different parts of the same vein, and they are mixed with a small quantity of dufrenite and thin films of colorless opal. In places iron oxide has penetrated the novaculite to a depth of 1 inch away from the joints.

DIERKS LUMBER & COAL CO.'S PROSPECT.

A manganese deposit in sec. 16, T. 4 S., R. 27 W., just east of the mining camp of Edgar & Co., was prospected in the spring of 1916 by the Dierks Lumber & Coal Co., which owns the entire section. The workings consist of four cuts on a low terrace at the edge of a stream flat that stands 10 feet above Little Missouri River. (See fig. 11.) They penetrate a bed of terrace gravel ranging from a few inches to 8 feet in thickness; three of them penetrate also both the Stanley shale and the Arkansas novaculite, and the fourth only the novaculite.

The novaculite penetrated by the workings is mostly massive, light colored, soft, and much jointed, but some of it is hard. It strikes S. 80° E. and in some places dips 80° N. and in others 80° S. The massive bed is 50 feet thick and is the upper division of the Arkansas novaculite. The middle and lower divisions of the formation are exposed farther south in Little Missouri River and on Sugartree Mountain. (See fig. 3, p. 76.)

The cut farthest west is from 5 to 6 feet wide, 3 to 8 feet deep, and 43 feet long. The manganese oxide found here consists of a few short veins less than 1 inch wide in the novaculite.

The next cut to the east is 3 to 15 feet deep and 50 feet long. A pocket of wad 2 feet wide and 4 to 5 feet long shows on the west side of the north end of the cut. Farther south on the west side there is a seam of wad 6 inches wide along the bedding, a pocket of ore 6 inches wide and 18 inches long, and a vein 6 to 10 inches wide that follows the bedding and shows on both sides of the cut. All these deposits are in the novaculite, and there are also numerous films and much thinner veins of wad in the novaculite and the adjacent layers of the Stanley shale. The wad is mixed with some red clay, from which it would be separated with difficulty.

The third cut to the east contains at its south end a pit 7 feet wide, 11 feet long, and 12 feet deep. A vein of ore from 8 to 24 inches wide is exposed in the northeast corner of the pit, several seams and pockets ranging from a fraction of an inch to 14 inches in thickness show on the east side, and one in the southeast corner is 2 feet thick. A vein of ore from 12 to 17 inches wide and three or four small pockets from 2 to 4 feet long and at most 12 inches thick have been found on the west side of the pit. All these pockets and veins occur along bedding planes and joints in the novaculite. The ore consists of hard psilomelane, showing in places banded, botryoidal, and stalactitic structure, but intimately mixed or banded with it is a small percentage of manganite. Several tons of ore free from rock have been taken from the pit and piled near by. Analyses of three samples of ore from this pit have been supplied by the Dierks Lumber & Coal Co. and showed 60.54, 55.36, and 45 per cent of manganese. The ore yielding the largest percentage of manganese was solid psilomelane, a more complete analysis of which is given on page 82.

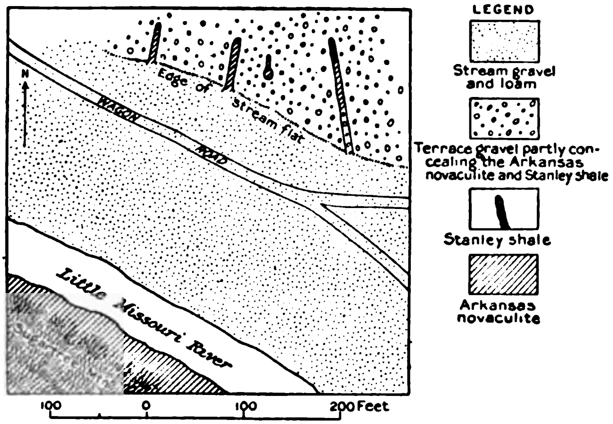

FIGURE 11.—Sketch map of workings on land of Dierks Lumber & Coal Co., Montgomery County, Ark.

The cut farthest east had badly caved at the time of the examination (Aug. 1, 1916). The only manganese visible is a pocket of manganiferous clay 4 feet long and 2 feet wide, and none of it has been placed on the dump.

The deposits exposed in these openings are small and some ore might be mined here at a profit, especially when manganese ores command high prices, as at present.

MORRELL CLAIM.

Penrose[1] describes a manganese deposit on the Morrell claim, in sec. 16, T. 4 S., R. 27 W., "on the east side of the Little Missouri

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[1] Penrose, R. A. F., jr., op. cit., p. 353.

River, at a point where that stream cuts through a novaculite ridge." This location accords very closely with that of the workings of the Dierks Lumber & Coal Co. just described, and the pit which he describes as follows may have been at the same place, but if so it has been enlarged or was not seen by the writer.

> A small pit sunk near the water level shows a hard, massive steel-blue manganese ore, often in stalactitic form. The ore is associated with black or brown glossy iron ore, and together they form a pocket from 1 to 3 feet in width in the novaculite. The ore frequently contains pockets of red clay.

SUGARTREE MOUNTAIN PROSPECTS.

On the north slope of Sugartree Mountain, a broken ridge bearing north of west, in sec. 17, T. 4 S., R. 27 W., a number of openings were made in the spring and summer of 1916 by Edgar & Co. Two tunnels have been driven into the base of the mountain. One of these, known as the Old Sugartree tunnel, extends west 50 feet into the mountain from the bottom of a ravine and penetrates the upper division of the Arkansas novaculite, which here dips 50° N. A very small amount of iron oxide shows on the surface rocks, and only stains of iron and manganese oxides were found in the tunnel. An air-compressing plant has been built 100 feet north of the mouth of the tunnel.

The second tunnel, known as the New Sugartree tunnel, is 2,000 feet west of the Old Sugartree tunnel and extends south 30 feet into the mountain. It was not visited. No manganese ore is said to have been found in the shale that was penetrated. Compressed air for drilling was piped from the plant at the other tunnel.

A north-south cut, known as Sugartree prospect, is 500 feet east of the Old Sugartree tunnel and 75 feet above the base of the mountain. It is 75 feet long and 15 feet deep in the deepest part and is in massive novaculite dipping 50° N. 40° E. and belonging to the upper division of the formation. Two veins of manganiferous iron oxide lie along the bedding. One of these is from 10 to 24 inches thick and is said to contain 10 per cent of manganese; the other is from 6 to 24 inches thick. Both are cut off at the north by what appears to be a fault. There is also a pocket of such oxide 3 feet long and 16 inches wide. This pocket and the two veins contain much clay, a little quartz, and a few pieces of novaculite.

A north-south cut 30 feet long and 2 to 3 feet deep has been made on the south side of the crest of a spur of Sugartree Mountain, 1,000 feet west of the Old Sugartree tunnel and about 250 feet above Little Missouri River. The massive novaculite that has been blasted out to form the cut contains a pocket of brown iron oxide 2½ feet long and 1½ feet wide and also a few veins of this mineral, all less than 1 inch thick. No manganese was found here.

A second north-south cut, which is 25 feet long, 8 to 10 feet wide, and 10 or 12 feet deep at the south end, is on the north slope of Sugartree Mountain, 1,600 feet west of the Old Sugartree tunnel and about 400 feet above Little Missouri River. Massive novaculite is revealed in the cut, but owing to the numerous joints its dip could not be determined. Veins and pockets of psilomelane associated with some wad and manganite were found in the novaculite through a north-south distance of 20 feet. Few of them are more than 6 inches thick, though one pocket containing a vug partly filled with clay is 3 feet long and 2 feet wide. The psilomelane is steel blue, shows botryoidal surfaces, and in places occurs in alternating layers with manganite whose radiating needle-like crystals are perpendicular to the surfaces of the curved layers. Some of the psilomelane also occurs in alternating layers with wad. These minerals occur in small quantity and probably can not be mined with profit. About a ton of them has been placed on the dump.

A third cut, 1,900 feet west of the Old Sugartree tunnel and about 450 feet above Little Missouri River, extends from north to south across the crest of a spur of Sugartree Mountain. It is 125 feet long, though 10 feet of rock at the crest has not been removed. The northern two-thirds of it—the part lying north of this unremoved portion—ranges from 4 to 10 feet in depth and is in massive novaculite dipping 55° N. 25° E. Only two very narrow veins of manganese oxide mixed with clay were found here. The south third of the cut is 10 feet deep at the deepest place and is in novaculite and decomposed shale separated by a band of hard brown ferruginous clay. A few hundred pounds of brown iron oxide was obtained from pockets in the novaculite.

RAINWATER PROSPECTS.

Nine small pits were made in June, 1916, by W. E. Rainwater, on the south slope of Sugartree Mountain, in sec. 18, T. 4 S., R. 27 W. Four of these are in a deep ravine at an elevation of about 150 feet above Long Creek. Two of the four are in the upper division of the Arkansas novaculite, which here stands nearly vertical, and they reveal thin, widely separated veins of hard and soft oxides of manganese mixed with some iron oxide. Only a very small quantity of these oxides has been taken out. The largest pieces on the dump weigh only a few pounds. The other two pits are in débris which includes some boulders of manganese oxide that weigh over 100 pounds and contain some fragments of novaculite. The character of the novaculite in these boulders indicates that they came from the same beds of novaculite that were penetrated by two of the pits.

The other five pits are in a ravine a quarter of a mile northeast of the pits just described and are all in massive novaculite, which here dips 90°. The pit farthest west shows no manganese oxide; one of the others reveals a pocket of manganese oxide a foot long and 3 or 4 inches wide; and the rest contain some float pieces of this oxide but none in place.

McKINLEY MOUNTAIN.

A manganese deposit on McKinley Mountain has been described as follows by Penrose:[1]

> Almost on the line of Polk and Montgomery counties it [McKinley Mountain] is cut through by Straight Creek, a tributary of Long Creek, the latter a branch of the Little Missouri River. Straight Creek passes through the mountain in a deep gulch, on either side of which the novaculite forms steep bluffs.
>
> A small pit has been sunk in the novaculite on the western side of this pass, in 4 S., 28 W., a few hundred yards west of the Montgomery County line. The pit shows manganese ore scattered irregularly and in limited quantities through a breadth of about 6 feet of the rock, and in some places the ore-bearing part of the rock is possibly still wider. The ore is a hard, compact steel-blue variety, frequently stained yellow or red by iron. It occurs throughout the rock in small seams and pockets, from a fraction of an inch to 4 inches in thickness. In some places the ore blends into the novaculite, turning it a deep black; in other places the line of separation is sharp and well defined. The following analysis shows the composition of this ore:

Analysis of manganese ore from McKinley Mountain, Polk County.

[R. N. Brackett, analyst.]

Manganese	49.24
Iron	2.04
Silica	2.98
Phosphorus	.38

Manganese peroxide, 71.41.

TELLUS DAVIS PROSPECT NO. 1.

The Tellus Davis prospect No. 1 is on the steep slope on the east end of He Mountain, about 300 feet above Long Creek, which flows through a gorgelike water gap separating He Mountain from Sugartree Mountain, near the east edge of Polk County, less than a quarter of a mile from the line. It is on a claim located by Tellus Davis, but in August, 1916, being prospected by the Mississippi Valley Iron Co.

The prospect is an east-west cut 25 feet long and 10 to 20 feet wide and when visited (July 31, 1916) showed a face of 10 feet at the west end. It is in massive beds of hard white fractured novaculite in the basal division of the Arkansas novaculite, which here dips 55° N. Small pockets and veins of psilomelane, the largest observed by the writer being 3 inches wide and the largest one reported in the removed rock being 6 inches wide, were found here and there along the joints and bedding planes throughout the width of the cut, and in places some manganese oxide penetrates the novaculite.

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[1] Penrose, R. A. F., jr., op. cit., pp. 353–356.

The psilomelane is hard and steel-blue and in places shows a concretionary structure and botryoidal surfaces. It is associated with a less amount of crystalline manganite, much of which shows radiating needles, together with iron oxide and clay. A narrow vein of low-grade siliceous brown iron oxide mixed with a small quantity of dufrenite and manganese oxide lies along the bedding of the novaculite on the south side of the cut.

TELLUS DAVIS PROSPECT NO. 2.

The Tellus Davis prospect No. 2 is on the south slope of He Mountain about 500 feet south of west from the prospect just described, on the same claim. It consists of a cut which at the time of visit (July 31, 1916) was 40 feet long, 8 to 10 feet wide, and 10 to 12 feet deep at the north end. It was then being worked by the Mississippi Valley Iron Co. Beds of massive shattered novaculite dipping 85° S. and belonging to the basal division of the Arkansas novaculite were encountered in making the cut. A number of veins of brown iron oxide, which if put together would make a continuous vertical vein not over a foot wide, were found along bedding planes. A lenticular vein 6 inches thick contains ferruginous manganese. Vugs and cracks in two or three of the veins contain a small quantity of dufrenite. In their weathered parts the dufrenite has changed its color from green to brown, and the iron oxide shows coatings of colorless opal.

W. A. DAVIS PROSPECT NO. 1.

The W. A. Davis prospect No. 1 consists of a north-south cut 38 feet long, a few feet wide, and 18 feet deep, near the east end of He Mountain, high on the south slope, less than half a mile from the east boundary of Polk County, and a quarter of a mile west of the Tellus Davis prospect No. 1. It is on a mineral claim located by W. A. Davis and was worked in the summer of 1916 by the Mississippi Valley Iron Co.

Massive novaculite, probably near the top of the lower division of the Arkansas novaculite, dipping 85° S., was blasted out to make the cut. Manganese veins ramify through a vertical zone of broken novaculite 4 feet wide on the east side of the cut and 6 feet wide on the west side and constitute less than half the bulk of the zone, but most of the ore that is free from novaculite fragments is confined to an irregular vein which on the east side is 12½ inches wide at a height of 6 feet above the bottom of the cut, 32 inches wide 3 feet above the bottom, and 7 inches wide at the bottom.

The ore consists of psilomelane and manganite, except that there is a little brown iron oxide south of the zone just described and on the west side of the cut. The psilomelane makes up the greater part of the deposit. It is massive, hard, and steel-blue, much of it has a banded structure and a botryoidal surface, and some is stalactitic. The manganite is in places intimately mixed with the psilomelane, but the two may be found together in a single narrow vein, occurring in alternating layers in which the psilomelane is the massive hard steel-blue variety and the manganite consists of plumose crystal growths whose fibers diverge toward the center of the vein. Some of the stalactites of psilomelane contain cores of manganite consisting of radiating fibers that diverge outward. Dendrites are common along the joints in the novaculite, and some of them are very delicate.

Some pieces of the psilomelane and manganite that are on the dump or that have rolled down the mountain slope contain angular fragments of novaculite and would require crushing and jigging to recover the ore, but 3 or 4 tons of these minerals are free of rock fragments. Four pieces of solid ore seen by the writer weigh about 250 pounds each.

It is possible that a small quantity of ore might be profitably mined at this locality, especially while the prices paid for manganese ores are high.

W. A. DAVIS PROSPECT NO. 2.

The W. A. Davis prospect No. 2 is a cut that was made in the summer of 1916 by the Mississippi Valley Iron Co. on a claim located by W. A. Davis, half to three-quarters of a mile southwest of the W. A. Davis prospect No. 1, near the base of a hill slope on the south side of Coon Creek, which here flows east along the south side of He Mountain. The cut extends 60 feet S. 30° W. into the hill and at its southwest end is 18 to 20 feet deep. The novaculite here belongs to the upper division of the formation and is in beds that dip 40° S. 30° W. and are cut by numerous joints. Thin veins of wad, in places mixed with brown and red oxides of iron, occur along some of these joints. They are usually less than half an inch thick, but one partly exposed pocket containing some red iron oxide and ferruginous manganese is 2 feet or more wide. Several feet of débris overlying the novaculite was penetrated in the cut, and embedded in it are boulders of psilomelane containing angular fragments of novaculite. The boulders have obviously rolled down the hillside from the parent pocket or vein.

Just west of the mouth of the cut is an exposure of a 2-foot vein containing manganese oxide, brown iron oxide, and specular hematite, but half of the vein is novaculite. Another exposure of novaculite showing two veins of hard massive psilomelane, one 1 to 6 inches wide and the other 12 inches wide, is 60 feet southeast of the mouth of the cut. From these veins many veinlets of psilomelane half an inch or less in width extend into the novaculite on each side and form a perfect network. This manganese-bearing zone may be the same as the 2-foot vein just described, and if so passes near the north end of the cut, in which it was not found.

HE MOUNTAIN.

A manganese deposit "on the summit of He Mountain, in Polk County, a little over a mile west of the Montgomery County line" is described by Penrose[1] as follows:

> A small pit 3 feet deep has been sunk on the ore, which is in small seams and pockets, rarely over 2 or 3 inches in thickness. The exact width of this ore-bearing part of the novaculite can not be seen, but the pit exposes a breadth of about 6 feet, and it is probably considerably wider. The ore is scattered through the rock in limited quantities. It is a hard, massive steel-blue variety, frequently having a concretionary structure and a mammillary surface, and is generally associated with more or less massive brown iron ore. The latter often incloses nodules of manganese or forms the outside layer of pockets of that ore. There are often small cavities in the novaculite, from 1 to 6 inches in diameter, lined with layers of iron and manganese ores. In some places both ores are sharply separated from the novaculite; in others they blend into it, staining it brown or black.

COON CREEK.

Penrose[2] furnishes the following description of a manganese and iron deposit on Coon Creek, a tributary of Long Creek that flows along the south side of He Mountain:

> In a novaculite hill bordering this creek on the south, half a mile southwest of the He Mountain locality just described, and in Polk County, 4 S., 28 W., another small pit has been opened on a deposit of manganese and iron. Both ores are in about equal quantities, and both are very much like those described on He Mountain. They either form the cement of a brecciated novaculite or occur as thin layers, nests, or pockets throughout the rock. The largest mass of ore seen came from one of these pockets and was 2 feet in diameter. Such masses, however, are rare.

EUREKA PROSPECT.

The Eureka prospect is at the east end of Brier Creek Mountain, in T. 4 S., R. 27 W., and is at the same level as the flat of Long

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[1] Penrose, R. A. F., jr., op. cit., pp. 356–357.

[2] Idem, p. 357.

Creek, 6 feet above the stream. Contorted ledges of massive white novaculite dipping at a high angle and striking east have been laid bare of débris through a distance of 20 feet from north to south, and a little solid rock has been removed. The work was done in 1916 by S. W. Sherrod. The débris on the slope just above the cut is a few inches thick and consists of fragments of novaculite. Manganite in small quantity cements some of this débris and occurs as veins between the ledges. It has apparently been deposited from the spring water that issues in a strong stream from the cut and higher on the mountain. Most of the veins are less than 2 inches thick, but one is 6 inches thick. A few hundred pounds of manganite could be obtained by careful hand picking of the material in sight.

BLUFF MOUNTAIN PROSPECT.

On the crest of Bluff Mountain, just north of Albert post office, in the southwest corner of Montgomery County, a pit 10 feet long from east to west, 6 to 7 feet deep, and 5 feet wide was made in May or June, 1916, by Walter Lyon and Foster Hays. It is in massive shattered novaculite in the lower part of the Arkansas novaculite, which here strikes east and stands vertical. A vein composed of psilomelane and manganite found at the east end of the pit is 18 inches wide at the bottom, where one-third to one-half its bulk consists of angular fragments of novaculite. Higher in the pit the vein widens to 3 feet and novaculite makes up the greater part of it. It continues to the west end of the pit, where it is only a few inches wide. Two pockets of ore a few inches wide were found within 18 inches north of this vein. They and the vein just described contain some red clay that has been brought in by ground water.

The deposit consists mainly of hard steel-blue psilomelane showing in places a botryoidal surface. A small quantity of manganite is in minute crystals intimately mixed with the psilomelane. The quantity of these minerals placed on the dump probably amounts to a ton.

LITTLE MUSGROVE MOUNTAIN.

Penrose[1] describes as follows a manganese deposit on the Webb Thornton claim, on Little Musgrove Mountain:

> Little Musgrove Mountain runs east and west in the extreme southwestern part of 4 S., 27 W., and is intersected by the Little Missouri River just above where that stream, issuing from the rocky gorge that it has cut through the novaculite ridges, flows into the less rugged country to the south. The mountain is composed mostly of gray novaculite dipping almost vertically and forming prominent bluffs on both sides of the river.

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[1] Penrose, R. A. F., jr., op. cit., pp. 353–354.

The Webb Thornton claim is in sec. 31, on a steep bluff in the south face of Little Musgrove. A soft black manganese ore (pyrolusite) occurs here in an equally soft white novaculite, easily crushed in the fingers. The largest exposure of ore is an oblong pocket 4 inches in its thickest part.

LEADER MOUNTAIN PROSPECTS.

Leader Mountain runs a little north of west in T. 4 S., Rs. 27 and 28 W., partly in Polk County and partly in Montgomery County. It lies between Brier and Blaylock creeks, and Little Missouri River passes through a gap at its east end. Manganese deposits have been found here and there along its crest and were explored during March and April, 1916, by F. P. Fay and Chester Stevens, who located 14 lode claims lying end to end from Little Missouri River westward about 4 miles into Polk County, and numbered consecutively 1, 2, 3, etc., from the east to the west. The claims have since been transferred to Edgar & Co.

The lower massive division of the Arkansas novaculite, which dips about 90°, occupies the crest of the mountain throughout most of the 4-mile stretch that has been explored, but in some places the middle division, cropping out farther north, occupies the crest. The two are separated by a breccia-like conglomerate which in places is 3 feet thick. The structure of the mountain is shown in figure 3 (p. 76). The manganese deposits are in the top of the lower division of the Arkansas novaculite.

A cut on the crest of the mountain extends diagonally across the boundary line between claims Nos. 3 and 4. It was blasted 2 to 3 feet deep for a distance of 40 feet in massive novaculite and reveals no ore. Two pits farther east on the mountain were not visited by the writer but are said to show no manganese ore.

A north-south cut 25 feet long is in massive novaculite just north of the crest of the mountain on claim No. 5. It reaches a depth of 6 feet at the deepest place and shows two veins of psilomelane, one of which is 4 inches wide and the other 2 inches wide. Some of the psilomelane contains angular fragments of novaculite.

Another north-south cut 30 feet long on the crest of the mountain, on claim No. 6, is in both the massive novaculite and the thin-bedded novaculite. It shows a vein of manganese oxide 4 inches wide and some stains of this mineral along cracks in the massive novaculite.

The north-south cut on claim No. 7 is 25 feet long and 5 to 8 feet deep and is on the crest of the mountain. The south end, which is in the massive novaculite, shows a little brown iron oxide in thin irregular veins along bedding and joint planes, and the north end is a thin-bedded novaculite. Thin films of chalcedony stained a bluish-green color with chrysocolla, a copper silicate combined with water, were found at one place in the cut.

Claim No. 8 has been prospected by means of a north-south cut 52 feet long and 7 feet deep on the crest of the mountain. The south end is in massive novaculite, but most of the cut is in thin-bedded novaculite. A stain of iron oxide was found in some of the cracks in the novaculite, but no manganese was found.

A north-south cut 50 to 60 feet long and 2 to 4 feet deep on the crest of the mountain, in claim No. 9, is mostly in massive novaculite dipping 65°–70° N., but the north end is in thin-bedded novaculite. A very small amount of brown iron oxide, some of which exhibits rainbow colors, was found here. No manganese oxide was found.

A cut 24 feet long and 4 to 6 feet deep just north of the crest, on claim No. 10, revealed no ore. A shallow pit on the same claim about 300 feet east of the cut shows a very small quantity of brown iron oxide.

Claim No. 12 has been prospected by means of a north-south cut 30 feet long and 3 to 6 feet deep. The north 10 feet of the cut is in contorted thin-bedded novaculite; the rest is in shattered massive novaculite, which is cut here and there by veins and pockets of manganese oxide, generally less than one-eighth of an inch thick. The largest pocket is 5 inches wide, and a foot of its length is exposed.

Two shallow north-south cuts on claim No. 13 show a very small amount of brown iron oxide but no manganese ore.

A north-south cut 72 feet long and 6 to 10 feet deep on claim No. 14, is in the massive novaculite on the north slope, high up near the divide in the saddle of Leader Mountain. An old pit in the north end was blasted out some 20 years or more ago, but it has been enlarged during the making of the cut. A zone of broken novaculite 6 feet wide and dipping 50°–60° N., parallel with the bedding, is near the north end of the cut and contains lenses of manganese oxides lying mostly along the bedding planes. The largest is 8 inches wide at the widest part. Some veins have been found along joints and reach a thickness of 3 inches. In places these oxides cement novaculite fragments. Farther south they were found in pockets and veins through a distance of 12 feet, but they constitute only a small percentage of the bulk of the rock. The manganese oxides are wad, manganite, and psilomelane mixed with much brown and red iron oxides.

In addition to the above-described localities, where manganese ore was found, the writer saw at several places along the crest thin veins in novaculite outcrops and pieces of manganese oxide scattered over the surface.

Penrose describes two manganese deposits on Leader Mountain. One of these is the Webb Thornton claim,[1] on the eastern part of the mountain in T. 4 S., R. 27 W., in Montgomery County, and is probably on one of the 14 recently located claims just described, but to judge from Penrose's description, given below, it was not visited by the present writer.

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[1] Penrose, R. A. F., jr., op. cit., p. 358.

> A pit 3 feet deep has been sunk on a deposit of manganese in the gray novaculite, and 500 pounds of ore are said to have been shipped. The manganese is a fine-grained soft crystalline ore often appearing in plumose forms. It occurs as the cement of a brecciated novaculite and forms from a tenth to as much as two-thirds of the whole mass. Occasionally the manganese is stained with a little iron, but much of it is comparatively free from that impurity.
>
> The pit shows a width of about 5 feet of this breccia, and though the same ore is seen on either side, it is in very much smaller quantities. The deposit runs along the top of the mountain but thins out in a short distance in both directions and is represented either by simply a stain or by thin layers of ore in the novaculite.

A deposit on the J. Guy Lewis claim, on Leader Mountain, not visited by the present writer, is described by Penrose[1] as follows:

> The J. Guy Lewis claim is on Leader Mountain, about 4 miles west of the Thornton claim and 2¼ miles west of the line between Polk and Montgomery counties. A small cut has been made on a deposit of hard, brittle, brown hematite, of a shaly structure. It occurs as pockets and lenticular beds in the novaculite, the largest seen being a pocket 2 feet thick. Such deposits are scattered irregularly through the rock on the summit of the mountain over a breadth of about 20 feet. The ore is traceable in intermittent outcrops for half a mile east and west from the cut, and also occasionally beyond these limits.
>
> Sometimes a few small masses of hard steel-blue manganese ore occur in the iron ore, especially at its contact with the country rock.

It is obvious from the above descriptions of the manganese deposits on Leader Mountain that at no place has ore been found in workable quantity.

COSSATOT MOUNTAIN PROSPECTS.

Cossatot Mountain is north of Mine Creek, a tributary of Cossatot River, and is a westward continuation of the Missouri Mountains. A number of old openings are on the mountain in the southeastern part of T. 3 S., R. 29 W., 2¼ miles east of Cossatot River, where this stream passes Spring Valley School. They are described by Penrose[2] as follows:

> Several small pits have been sunk for manganese on the summit of the mountain, and a tunnel 40 feet long has been run into the north side about 20 feet below the summit. The gray novaculite forms the crest of the ridge, and the siliceous shale comprises the slopes. The tunnel has reached the novaculite through the shale. The manganese is in the form of a crystalline pyrolusite, mixed with a hard, massive ore, and occurs in irregular nests from a quarter of an inch to 3 inches in diameter and in thin seams from a sixteenth to a

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[1] Penrose, R. A. F., jr., op. cit., p. 358.

[2] Idem, pp. 370–371.

quarter inch in thickness. Such bodies of ore are scattered irregularly through a breadth of about 40 feet of novaculite. The manganese forms but a small portion of the ore-bearing stratum, and, except in the richest places, the aggregate amount of the scattered bodies of ore would form a very small percentage of the mass.

GRANT PROSPECT.

The Grant prospect consists of a cut about a quarter of a mile east of Three Oak Gap, on the south slope of Cossatot Mountain. The cut is 10 feet long, 5 to 6 feet wide, and 4 to 6 feet deep, and was blasted 20 years or more ago in projecting ledges of the upper division of the Arkansas novaculite. Pockets and veins of manganese and iron oxides reaching a width of 9 inches were found along cracks in the massive novaculite, which has been minutely fractured and somewhat faulted, as shown by the presence of slickensides. Some of these oxides cement many of the fractured pieces. The manganese oxide is more abundant than the iron and consists of hard steel-blue psilomelane, some of which contains small crystals of manganite. The iron oxide is represented by both brown and red oxides.

About a ton of manganese ore that has been removed from the cut and since scattered around it on the surface could be separated from the novaculite by hand picking. It is said that several hundred pounds of this material has been carried away as specimens.

A shallow pit from which a little manganese oxide, a larger amount of brown iron oxide, and some red iron oxide have been removed is about 50 feet northeast of the cut just described, on the same ledges of novaculite.

A pit revealing massive brown iron oxide along bedding and joint planes has been dug about a quarter of a mile west of the above-described locality, on the same bed of novaculite. Very little manganese was seen here.

BIG FORK.

A number of small openings on manganese deposits a few miles southwest of Big Fork, in Polk County, have recently been made by farmers. None of the localities were visited by the writer.

OTHER DEPOSITS IN POLK COUNTY.

Some manganese deposits in Polk County that were not visited by the writer are described by Penrose,[1] as follows:

> *Pointed Rock Tunnel.*—Pointed Rock Tunnel is in 4 S., 28 W., sec. 19, and is the property of the Arkansas Development Co. A deposit of hard laminated brown hematite occurs here, interbedded in gray and black siliceous shale. The rocks stand vertically or dip at angles of 70°-80° N. and form part of a

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[1] Penrose, R. A. F., jr., op. cit., pp. 358-371.

low hill. A tunnel has been run in at the foot of the hill, just above the level of a small creek, and follows the iron ore in the direction of the strike of the rock for about 100 feet. The ore occurs in a series of parallel strata from 1 to 12 inches in thickness, separated by similar strata of shale, or of clay which has resulted from the decomposition of the shale. The northern part of the hill is composed of the gray novaculite, and the ore occurs near the contact of the shale with that rock. The rocks strike across the hill, and the ore can be traced a distance of a quarter of a mile over the summit and down to a creek on the other side. The alternating strata of iron ore and shale occupy together a belt varying from 20 to 50 feet in width. Sometimes the ore in a given stratum runs out and is represented by rock for a few feet, but it usually appears again beyond. In places the combined thickness of all the ore strata, if brought together, would amount probably to over 5 or 6 feet; in others it would not be a quarter of that thickness.

Tall Peak Mountain.—Tall Peak Mountain forms part of a long novaculite ridge known as Raspberry Mountain, which runs in a general direction a little north of west across the headwaters of the Saline River and the Harris Creek fork of the Cossatot River. On the lower part of the northern slope of Tall Peak Mountain, on a claim controlled by the Arkansas Development Co., in 4 S., 29 W., sec. 24, the gray novaculite is impregnated with manganese for a width of about 20 feet. The ore-bearing part of the novaculite is at the contact of that rock with the shale and protrudes in a low ledge above the surrounding surface. Its relation to the different rocks is shown in the accompanying figure [fig. 12], which represents a north-south section across a part of the claim.

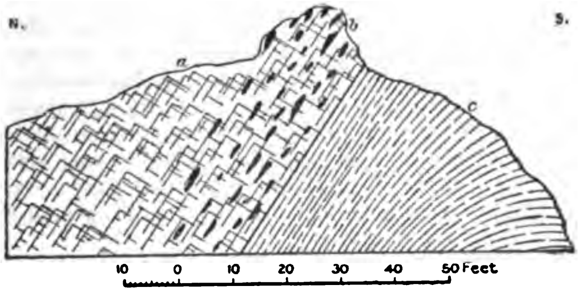

FIGURE 12.—Section on the north slope of Tall Peak Mountain, Polk County, Ark., showing the occurrence of manganese ore in the gray novaculite. (After Penrose.) *a*, Gray novaculite; *b*, manganese-bearing part of the novaculite (black parts represent ore); *c*, siliceous shale.

The ore is in pockets and lenticular layers scattered through the rock, the largest seen being 2 feet long by from 3 to 6 inches in thickness. It occurs both in the form of a hard massive steel-blue ore and as a finely crystalline variety, the crystals frequently being grouped in a plumose form and having a brown streak. Occasionally the manganese contains small quantities of iron, but it is generally comparatively free from that impurity.

On the west the ore-bearing stratum disappears under the gravel of a small creek; on the east it rapidly thins out on the slope of the mountain and is replaced by the pure gray novaculite.

The usual strata of brown hematite, from 1 to 12 inches in thickness, occur in the siliceous shale shown in the figure to the south of the manganese. A tunnel was run into this rock with the intention of reaching the manganese but was not continued far enough to do so. At the mouth of the tunnel the shale is almost horizontal, but to the north it rapidly curves around, and when it reaches the novaculite it is dipping at the same steep angle as that rock. The shale has in many places been decomposed into a fine gray clay containing layers of the unaltered rock. The following analysis shows the composition of the manganese ore on this property:

Analysis of manganese ore from Tall Peak Mountain, Polk County.

Manganese	52.16
Iron	4.00
Silica	.24
Phosphorus	.39

Manganese peroxide, 77.60.

East Hannah Mountain; the High Peak.—The High Peak of Hannah is a part of the Hannah Ridge, about 3 miles east of the Cossatot River. On the south slope of the mountain, and probably about 300 feet from the summit, is a deposit of brown iron ore in the gray novaculite. The deposit is 3 feet in the widest part, and about two-thirds of it is composed of ore. It follows along the slope of the mountain for about 10 feet and beyond these limits becomes thin and is often represented only by a stain.

East Hannah Mountain; the William Allen claim.—The William Allen claim is on the north side of East Hannah Mountain, near its base, about a mile and a half east of the Cossatot River. It is on what is known as the Condor " lode," which contains manganese ore in seams and pockets from a fraction of an inch to 8 or 10 inches in thickness, scattered through the novaculite. The latter size, however, is exceptional, and the largest mass seen measured 3 by 6 by 10 inches. The ore is of both the crystalline and massive varieties, the former often showing a plumose structure. The massive variety is hard and often in stalactitic and mammillary forms. The manganese is associated with a glossy black iron ore.

East Hannah Mountain; the west end.—On the western end of East Hannah Mountain, in the neighborhood of the Cossatot River, both manganese and iron are scattered in small quantities through a belt of novaculite varying from 5 to 20 feet in width. In some places the ore is iron and in others manganese; in still others both ores are mixed together in varying proportions. They occur in thin seams along lines of bedding or joint cracks, or as the cement of a brecciated novaculite; in places also they are in small nodules and often form only a stain in the rock. The rocks dip uniformly to the north at angles of from 60° to 80°.

West Hannah Mountain; the William Allen claim.—This one of the William Allen claims on West Hannah Mountain is a quarter of a mile west of the Cossatot River, on the north slope of the mountain, and on what is known as the Fawn " lode." The manganese is in the gray novaculite, near its contact with the shale. The ore impregnates the rock for a width of 10 feet in small seams and pockets from a quarter of an inch to 3 inches in thickness and is both massive and crystalline. The manganese is associated with small quantities of brown iron ore.

West Hannah Mountain; the Bowen claim.—The Bowen claim is on the summit of West Hannah Mountain, at its extreme west end, 4 miles west of the Cossatot River, and overlooks the valley of Brushy Fork. Manganese is found here in the crystalline form with smaller quantities of a hard massive ore. It occurs in thin discontinuous seams occupying cracks and joints in the novaculite and sometimes forming the cement of a breccia. The largest mass of solid ore visible is 3 inches in thickness and 3 feet in length, thinning out at both ends.

Buckeye and Shadow Rock mountains.—Buckeye and Shadow Rock are names given to different parts of a novaculite ridge which runs parallel to and immediately north of East Hannah Mountain in 4 S., 28 and 29 W. In its eastern part it is known as Buckeye Mountain until within about 4 or 5 miles of the Cossatot River, and from that on to the river it is known as Shadow Rock Mountain. The ridge rises from 500 to 800 feet above the Cossatot, its average height being much lower than that of East Hannah to the south. It is separated from the latter ridge by a deep ravine which marks the course of Short Creek, a tributary of the Cossatot.

A large number of claims have been taken on exposures of manganese and iron on both ends of the mountain, and the principal ones are here described:

1. Manganese Mountain: Manganese Mountain is a small spur of Buckeye Mountain, running out from the south side of the ridge about 5 miles east of the Cossatot River. Manganese is found here in the gray novaculite in the form of a hard massive steel-blue ore, blending at times into a semicrystalline ore. It is generally in the form of flat, botryoidal, or concretionary masses, often having hollow interiors. It tends to follow lines of bedding, but it also runs off in joint cracks. The bedded layers are the larger, and one of them measured from 3 to 6 inches in thickness and 4 feet in length. The seams in the joint cracks rarely measure over a quarter of an inch in thickness, though they are often so numerous as to honeycomb the rock in all directions.

The accompanying figure [fig. 13] shows the character of the bedded deposits in the side of a small opening on the summit of the spur. It will be observed in the figure that the lenticular layers of ore lie intermittently along different planes of stratification, and that they are separated along the same planes by barren areas, which, however, are generally stained with iron ore or manganese. Sometimes the layers of ore are simply flat concretions. The following analysis shows the composition of the ore from this locality:

Analysis of manganese ore from Manganese Mountain, Polk County.

Manganese	42.75
Iron	2.72
Silica	10.46
Phosphorus	.45

Manganese peroxide, 62.75.

2. The Walston claim: The Walston claim is on the same hill as the last-named locality and a quarter of a mile northwest of it. Layers from 2 to 6 inches in thickness of glossy black or dark-brown iron ore are interbedded in the gray novaculite. The ore also runs across the stratification in fractures in the rock. The deposit occurs at the crest of a small, local anticline, and the layers of ore dip off in both sides of the pit. No manganese was seen at this opening.

Another one of the Walston claims is near the last and at the point where Manganese Mountain joins the main Buckeye Mountain. Iron ore similar to that just mentioned has been found here in a small pit now mostly filled up. It is said to have been in larger quantities than at the last place.

C. C. Avant claims.—Mr. Avant owns several claims in the vicinity of the upper waters of the Cossatot River, and two of them are here described:

1. Manganese: This claim is in 4 S., 29 W., sec. 6, on a novaculite ridge running parallel to and north of West Hannah Mountain. The ore-bearing stratum is known here as the Eldridge "lode," and the Avant claim is near its eastern end, a few hundred yards west of where the ridge slopes off to the valley of the Cossatot River. Manganese ore is found in the gray novaculite on and near the summit of the mountain and is of a hard steel-blue variety, often in stalactitic and mammillary forms. The ore-bearing part of the rock varies from 1 to 5 feet in thickness and contains the ore in thin seams, from a

fraction of an inch to 8 inches in thickness, following the stratification or occupying joints and cracks. The ore-bearing deposit dips to the north with the inclosing rock, at angles from 70° to 90°, and is traceable for several hundred yards along the mountain, when it thins out, widening again to the west.

2. Iron: This claim is in 4 S., 30 W., sec. 1, about a mile west of the last locality (claim 1), on the south slope of the same mountain, and about a quarter of the way from the summit. Here the ore-bearing stratum is represented mostly by iron ore, though small quantities of a black massive manganese ore sometimes occur. The iron ore is in the form of a brown hematite and forms the cement of a brecciated novaculite, in which the rock masses vary from a fraction of an inch to 6 inches in diameter and are sometimes stained throughout by iron. This mixture of rock and ore has a width of about 30 feet on the slope of the mountain, but only a small part of it is composed of ore.

The Arkansas Development Co.'s mine.—The Arkansas Development Co.'s mine is in 3 S., 30 W., sec. 27, and is locally known as the Ward manganese mine, from the name of the former superintendent. It is near the headwaters of the Brushy Fork branch of the Cossatot River, on a novaculite ridge which rises over 400 feet above the creek. It is the property of the Arkansas Development Co., and was worked during the year 1888 and until April, 1889, when operations were stopped. During this time a shaft 142 feet deep was sunk on the north slope of the ridge, and a tunnel about 500 feet long was run into the northern side near the level of Brushy Fork. About 20 tons of ore are said to have been taken from the shaft; none was found in the tunnel.

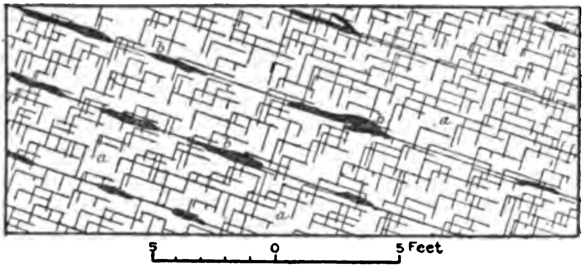

FIGURE 13.—Section in a pit on Manganese Mountain, Polk County, Ark., showing the occurrence of manganese ore in the gray novaculite. (After Penrose.) *a*, Gray novaculite; *b*, manganese ore.

The summit and upper slopes of the ridge are composed of gray novaculite, while on the north side, where the tunnel has been run, the lower slopes are composed of black siliceous shale. The manganese occurs in the novaculite in the form of crystalline pyrolusite, associated with a hard iron-gray massive ore, the former often coating the latter as an incrustation, and both occurring in kidney-shaped or stalactitic forms. Sometimes small quantities of a black iron ore (limonite) showing a glossy, brilliantly iridescent surface, are associated with the manganese, but a large part of the latter is free from such impurity.

The manganese-bearing deposit varies from 1 to 2 feet in thickness and dips almost vertically. The ore, however, composes only a small part of this and usually occurs as thin seams and pockets from a fraction of an inch to over 2 inches in thickness, scattered irregularly through the rock. Occasionally, however, the ore widens out locally into pockets of somewhat larger size. Sometimes the ore disappears altogether or is represented only by a stain in the rock, but widens out again at irregular intervals.

Other openings made by the Arkansas Development Co. on Brushy Fork.[1]—Several other smaller openings have been made by the Arkansas Development

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[1] Several properties owned by this company elsewhere in Polk County have already been described (pp. 116–118).

Co., on both manganese and iron, in the same neighborhood as the Ward mine. The most important are given below:

1. The Jumbo pit: The Jumbo pit is 500 yards east of the Ward mine, on the north slope of the same ridge. Manganese ore impregnates the novaculite in the same way as at that place. A pit 15 feet deep and 8 feet square has been sunk, and on all sides of it are seen thin, irregular, and discontinuous "stringers" of ore, from 1 to 5 inches in thickness, either in lines of bedding or in joint cracks. The novaculite is generally stained a buff or a brown color and is soft, often disintegrating into a powder.

2. Tunnel No. 2: Tunnel No. 2 is little over half a mile east-northeast of the Ward mine. It is 20 feet long and was run into a gray siliceous shale, on a deposit of brown iron ore. The ore is a brown hematite, interbedded in the rock in irregular pockets, from a few inches to a foot or more in thickness. The ore is laminated and has much the same structure as the inclosing shale, into which it blends both laterally and vertically. The quantity of ore is very limited.

Two hundred yards northeast of this tunnel is a small pit on a similar ore in a similar rock. The ore frequently forms the cement of a breccia of fragments of the inclosing rock and is irregularly scattered through a stratum 3 feet thick. The shale in contact with the ore is often much decomposed and exists in the form of a fine siliceous powder.

3. Shaft No. 3: Shaft No. 3 is over a half mile northeast from the Ward mine and is a pit 8 feet square and 20 feet deep, sunk for manganese in the gray novaculite. The ore occurs in small nests and thin discontinuous seams, from 1 to 6 inches in thickness. Sometimes they follow joints, but the largest seams are in the bedding planes of the rock, which pitches to the southwest with an undulating dip of about 30°. The deposits in the joint cracks frequently cross those in the lines of bedding, showing that the ore in the bedding planes was deposited previously to that in the joints.

4. Shaft No. 4: Shaft No. 4 is near shaft No. 3, is about the same size, and has been sunk in the novaculite for manganese. The ore is a hard, massive variety in a mammillary form and occurs as in shaft No. 3, in lines of bedding and in joint cracks. The largest seam measured was 4 inches thick and 4 feet long, representing a lenticular layer.

Little Manganese Mountain.—Little Manganese Mountain is the name given to the western end of the novaculite ridge running parallel to and a mile south of East Hannah Mountain. Iron and manganese are found on it a mile east of the Cossatot River, where the mountain begins to slope down to the valley of that stream. The claim is owned by Mr. William Allen and is known as the Cave "lode." The ridge here is composed mostly of gray novaculite, dipping at angles of from 45° to 60° N. and overlain on the northern slope by the siliceous shale. In the novaculite near the contact with the shale are discontinuous strata of brown hematite, associated with smaller quantities of manganese and varying from a fraction of an inch to 4 inches in thickness. They run sometimes continuously in the direction of the ridge for 50 or 60 feet and then thin out, appearing again beyond. The manganese is in much smaller quantities than the iron ore and occurs in nodules and thin seams. As a rule the iron ore seems to be largely confined to the contact of the novaculite and shale, while the manganese is found not only there, but also in the novaculite, farther from the contact line.

HATTON.

Prospecting was done during the summer of 1916 on a number of manganese deposits on the novaculite ridges in the vicinity of

Hatton. The following information on that locality has been supplied by George Hammond, of Wickes, Ark.[1]

A tract of land owned by Jacob Hoblitzel in secs. 13 and 14, T. 5 S., R. 32 W., has been prospected and several hundred pounds of manganese ore obtained here was shipped to a chemist in Fort Smith, Ark., for experimental work.

Land owned by M. H. Doty in the SW. ¼ sec. 18, T. 5 S., R. 32 W., has been prospected, but only samples of manganese ore have been shipped.

Considerable prospecting has been done in sec. 10, T. 5 S., R. 32 W., on land owned by E. L. Henson and leased by O. W. Thompson.

Prospecting had been temporarily discontinued when the writer was at Hatton (July 23, 1916), and he did not visit the workings.

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[1] Letter dated Dec. 9, 1916.

TIN RESOURCES OF THE KINGS MOUNTAIN DISTRICT, NORTH CAROLINA AND SOUTH CAROLINA.

By Arthur Keith and Douglas B. Sterrett.

INTRODUCTION.

The Kings Mountain district, in which the tin ores here described are found, is included in the Gaffney, Kings Mountain, Lincolnton, and Gastonia quadrangles mapped by the United States Geological Survey. The district is almost equally divided between North Carolina and South Carolina, the part in North Carolina being a little larger.

The examinations on which this report is based were made by the authors in preparing the Gaffney-Kings Mountain and Lincolnton-Gastonia folios of the Geologic Atlas of the United States. A previous and less detailed examination was made by L. C. Graton.[1] Mr. Sterrett carried on his work in 1908 and in subsequent years up to 1914. The district has also been examined in detail by Mr. Keith, in company with Mr. Sterrett, with special reference to the general geology and the formations and structures of the region.

GEOGRAPHY.

The Kings Mountain district is in the central part of the Piedmont Plateau, of which it may be considered a typical area. The country is one of broad, flat or gently rolling ridges that become more broken near the larger streams, where deep valleys have been cut. The sky line as viewed from the higher ridges is that of a nearly level plain, above which stand a few elongated hills and mountains, called monadnocks. Most of these hills are in a narrow central northeastward-trending belt.

A few low ridges rise above the plateau surface in the southeastern part of the Lincolnton quadrangle, but these do not compare in height and roughness with the more prominent peaks in the Kings Mountain quadrangle, to the south. The smooth, broad ridges pass rather sharply into steeper slopes at the foot of the monadnocks and near stream valleys. Many of the valleys in these quadrangles are rather broad and have nearly flat bottoms, but some are V- with steep walls. The relief where the rivers and larger stre cutting through hard rocks is considerable, and the hillsi steep and rocky.

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[1] Graton, L. C., Reconnaissance of some gold and tin deposits of the southern Appalachians: U. S. Geol. Survey Bull. 293, 1906.

Characteristic developments of the rolling upland country seen between Kings Mountain and Cherryville and on to the west beyond Floy. The relief for considerable distances alc ridges in these areas is low, and the side valleys are shallow cultivated lands are smooth fields with deep residual soil an scattered outcrops of rock.

The plateau ranges in elevation from 750 to 1,050 feet ab level, but most of it is between 850 and 1,000 feet. The highes are in general on the northwest, and there is a decided genera to the southeast. The stream valleys are cut 50 to 200 feet the general plateau surface, and the residual hills, or monad stand from 100 to 700 feet above it. The highest points are Mountain Pinnacle, 1,705 feet, and Crowders Mountain, 1,62 above the sea.

The town of Kings Mountain is situated at an elevation of feet on the principal divide, which has a general northwest between the drainage basins of Catawba and Broad rivers and rates the district into nearly equal parts. Broad River takes a easterly course through the Gaffney quadrangle and across a of the Kings Mountain quadrangle. Its principal tributari Kings, Bullocks, Buffalo, Cherokee, and Thicketty creeks and Broad River. The chief tributaries of Catawba River are I Crowders, Allisons, Clark, and Beaverdam creeks and the Fork of Catawba River.

The Southern Railway runs from southwest to northeast thr the middle of the district and connects most of the principal t including Gaffney, Blacksburg, Kings Mountain, Bessemer City Gastonia. The Kingville & Marion branch of the Southern way runs from southeast to northwest and crosses the main li Blacksburg. A branch of the Seaboard Air Line Railway southwestward through Lincolnton and Cherryville. Between semer City and Gaffney the Southern Railway passes within a or two of the tin belt, and no known deposit of tin ore in this b more than 3 miles from a railroad. (See Pl. IV.)

DESCRIPTIVE GEOLOGY.

PIEDMONT PLATEAU.

The rocks of the Piedmont Plateau are of both igneous and s mentary origin. Both kinds of rock have been metamorphosed many places. In some localities the metamorphic igneous and s

mentary rocks are not sharply distinct, for the metamorphism has been so extreme that nearly all traces of original sedimentary or igneous nature have been obliterated. In many places also the metamorphic igneous rocks are not sharply separable from the ordinary igneous rocks, for a single intrusive mass may have become metamorphosed in some parts, especially near its borders, during processes of mountain building and may show little or no evidence of change in other parts, particularly in the interior.

The metamorphic rocks of sedimentary origin in the Piedmont Plateau consist of gneisses and schists, the principal varieties of which are those characterized by muscovite or biotite, garnet, kyanite, staurolite, chlorite, sericite, ottrelite, and, in some rocks, quartz and calcite. All these varieties have resulted from the metamorphism of ancient sedimentary rocks such as conglomerates, sandstones, shales, limestones, and numerous intermediate kinds. By metamorphism sandstone became quartzite, impure or shaly sandstone became graywacke and gneiss, shale became schist, and limestone became marble. Variations in composition of the original sediments are represented by variations in the metamorphic rocks. Some of the sediments were in part of volcanic origin, such as volcanic ash or tuff laid down in water with varying amounts of detrital material derived from ordinary land waste. The metamorphism of these rocks has produced varieties of crystalline rocks transitional between those of purely sedimentary origin and those of purely igneous origin.

The metamorphism of some of these igneous rocks has been so extreme that they have become mica and garnet gneisses or schists that are indistinguishable from similar foliated rocks of sedimentary origin. Diorite and many basic igneous rocks have become hornblende gneiss, hornblende schist, chlorite schist, serpentine, soapstone, etc.

The igneous rocks of the Piedmont Plateau include a wide range of such rocks as are generally classed as granite, diorite, gabbro, pyroxenite, peridotite, porphyries, and diabase, with many intermediate varieties. Some have been intruded as batholiths, laccoliths, sills, dikes, or stocks; and others have been poured out as surface flows. The eruptions occurred during several epochs. The older intrusives have been more or less metamorphosed and, as stated above, are not everywhere sharply distinct from the metamorphosed volcanic and sedimentary rocks.

The strike of the formations of the Piedmont Plateau is generally northeast, or approximately parallel with the trend of the plateau and the bordering Appalachian Mountains, but locally the strike may be nearly at right angles to the prevailing trend. The dip of the formations is generally high but is variable, and as a rule it is southeast.

KINGS MOUNTAIN DISTRICT.

The district here described contains both metamorphic and igneous rocks, and the metamorphic rocks include some of sedimentary and some of igneous origin. In age the rocks range from Archean to Triassic. The Archean rocks occupy most of the district, especially its northwestern and southern parts. Through the middle of the district from southwest to northeast extends a belt of probably Cambrian rocks, including schists, quartzites, conglomerates, and marble, and of probably Algonkian rocks, including schists and tuffs. The Archean rocks have been cut by masses of later igneous rocks—granites, diorites, etc.—some of which are of great size. The diorite and one body of granite are pre-Cambrian; two other granite masses are late Paleozoic, perhaps Carboniferous. The formations that are associated with the tin deposits are the Carolina gneiss and Roan gneiss, of Archean age; the Bessemer granite, of pre-Cambrian age; the Whiteside granite and, especially, tin-bearing pegmatites of late Paleozoic age. The other formations represented in the district are not associated with the tin ores and will not be considered here.

STRUCTURE.

The rocks of the district have been extremely folded, to some extent faulted, and greatly metamorphosed. The structural features resulting from extreme compression run in general northeast, as is usual in the Appalachian Mountains and Piedmont Plateau. The Cambrian (?) and Algonkian (?) rocks lie in a corrugated synclinal trough between uplifted belts of Archean gneisses and later granites. This trough is double, having two major downfolds, between which pre-Cambrian rocks reach the surface. In the Archean rocks along the northwest side of this general trough, at distances of 2 miles or less from their border, lies the tin belt. In the area between Kings Mountain and Gaffney this boundary between the Cambrian (?) and Archean rocks coincides with a fault that dips about 45° NW. The folds of the rocks in the tin-bearing belt range in trend between N. 60° E. and N. 20° E. and are comparatively regular and straight, as are also the folds of the Cambrian (?) and Algonkian (?) formations. On both sides of this middle belt there are many and great local departures from this regular structure. In the tin belt the rocks dip northwest at various angles, usually high. Most of the minor folds are closed and overturned and are very difficult to detect. The faults, doubtless numerous, are likewise obscure, and comparatively few have been traced. The only one known to have affected the tin belt is the boundary fault mentioned above.

CAROLINA GNEISS.

Distribution.—The Carolina gneiss, so named because of its extensive development in the Carolinas, is the most widespread formation in the district, as well as the oldest rock in the region. It is most prominently developed in the northwestern part of the district, and no large body of it is known southeast of the middle syncline of Cambrian (?) rocks. It has been cut into elongated and irregular-shaped bodies by masses of intrusive igneous rocks.

Character.—The Carolina gneiss consists of an immense series of interbedded gneisses and schists, prominent among which are mica gneiss and schist, garnet gneiss and schist, and kyanite gneiss and schist, with intermediate varieties and granitoid layers. Less abundant are gneisses and schists characterized by graphite or staurolite. Practically all the gneiss and schist contains quartz and mica, either muscovite or biotite, but rock that contains other minerals, such as garnet or kyanite, receives its name from these. Thus garnet gneiss or schist may contain either muscovite or biotite or both, quartz, feldspar, and numerous accessory minerals.

The mica gneisses and schists are so diverse in texture and composition that it is difficult to give a general description of them. The schists range in texture from coarsely crystalline to fine grained and in many places exhibit variations both in grain and in mineral composition within a thickness of a few inches. Most of them are composed of quartz and biotite or muscovite, with or without feldspar, magnetite, and various other minerals. In some the mica scales are fine to medium in size; in others they are as much as a quarter of an inch in diameter. The coarsely crystallized kinds are commonly associated with granite or pegmatite. The quartz and other minerals of the schists occur in aggregates showing about the same range in grain as the mica scales.

The schists are strongly foliated in consequence of the grouping of their mineral grains with their longer dimensions roughly parallel. The cleavage of the mica is parallel with the schistosity of the rock, and the scales wrap or fold around the ends of the other minerals or inclose lenticular masses of them. The quartz of the schists occurs in flattened or lenticular aggregates of small grains. These lentils may be separated or connected by small seams of quartz.

The structure of the schists renders them fissile, cleavage readily taking place both between the different mineral grains and through the more cleavable minerals, such as mica. In some schists cleavage in more than one direction has been developed by compression of the rocks in more than one period and in different directions. In some rocks the later cleavage, or "slip cleavage," is due to a parting or slipping developed along a series of small, close folds. In places mica scales have been formed along such slips, so that the structure closely resembles the original schistosity. Another variation in the mica schists is due to the development of scattered coarse mica crystals with the cleavage turned about at right angles to the schistosity. Such crystals have been developed by metamorphism later than that by which the schistosity was produced.

The mica gneiss of the Carolina is varied in texture and composition. In one sense it may be considered as composed chiefly of a large variety of interlayered schists, the gneissic structure being due to the association of numerous unlike layers. A portion of the Carolina gneiss, however, is composed of granitoid layers that consist of feldspar, quartz, and either or both muscovite or biotite with numerous accessory minerals. The texture of this variety is commonly much coarser and the foliation less pronounced than in the mica schists. Some of this gneiss has developed from homogeneous rocks and consequently has a rather uniform texture and banding. Other masses have been derived from rocks of diverse composition and consequently show strong banding with contrasts in texture.

The ordinary gneisses and schists grade into other kinds by the addition of such minerals as garnet, kyanite, and graphite. Where garnet and kyanite are abundant and occur in large crystals the texture of the schists differs substantially from that of ordinary mica schist. Garnet and kyanite tend to crystallize with but little adaptation to the parallel arrangement of the other minerals of the schists and accordingly produce a porphyritic texture. Graphite, however, occurs in plates or scales parallel with the mica, and its presence does not change the general texture of the schists.

The interlayering of and gradations between mica schists and gneisses and those containing garnet and kyanite are so prevalent and intimate that it is practically impossible to show all varieties separately on a map.

ROAN GNEISS.

Distribution and name.—The Roan gneiss, named from Roan Mountain, on the North Carolina-Tennessee border, where the formation is extensively developed, occurs in large masses and in belts or dikelike bodies cutting the Carolina gneiss in practically the whole of the district. It forms most of the surface at the south border of the district, and in the north-central part it occurs in areas 2 to 5 miles wide, most of which have very irregular outlines, especially near the intrusive bodies of Whiteside granite.

Character.—The Roan gneiss consists chiefly of hornblende schist, hornblende gneiss, schistose diorite, and diorite. In places there are intercalated layers of mica schist and gneiss and garnet schist and gneiss not essentially different from similar rocks of the Carolina gneiss. The hornblende beds are black or dark greenish black in color, and the other schists are light to dark gray. The hornblende rocks are of uniform composition, even in rather large bodies. Massive diorite occurs in some of the larger masses of Roan gneiss, but most of the rock is somewhat schistose. Very schistose varieties that are apparently composed almost wholly of hornblende are called hornblende schist but are as a rule merely modifications of the diorite. In places hornblendic layers are separated by layers of quartz or feldspar, and the rock is designated hornblende gneiss. The hornblendic rocks range from those of fine texture to those in which some of the crystal grains measure half an inch across. The mica and garnet gneisses and schists within the Roan gneiss are probably masses of the Carolina gneiss included in the original diorite at the time of intrusion or subsequently interfolded with the Roan gneiss. Pegmatite occurs through much of the Roan gneiss, as in the Carolina gneiss.

BESSEMER GRANITE.

Distribution and name.—The Bessemer granite crops out in several broad bands in the central part of the district. The main band lies southeast of the general central trough of Cambrian(?) sedimentary rocks, and smaller bodies of the granite appear between its two main parts. One of these minor bodies expands to the north and in the Lincolnton quadrangle underlies Bessemer City, for which it is named.

Character.—The Bessemer granite is a medium to fine grained muscovite-biotite granite near quartz monzonite in composition. It is locally porphyritic. In all outcrops it has a strong schistose structure, and in many places it has been metamorphosed into white and gray quartz-sericite schists that bear no resemblance to the original granite. Only in certain favorable outcrops can the gradation from the schistose granite to sericite schist be seen. The porphyritic varieties of the granite have in some places been metamorphosed into quartz-augen sericite schists or "bird's-eye" schists.

In the less altered parts of the granite the constituent minerals are quartz, orthoclase, oligoclase, muscovite, biotite, and a little magnetite and zircon, with secondary clinozoisite and chlorite. In the metamorphism of the Bessemer granite to quartz-sericite schists the muscovite has been largely recrystallized into finer scales and the potash feldspar has passed into fine scaly sericite. The quartz has in part recrystallized, but the larger grains or phenocrysts retain more nearly their original size and position. Much silica has been set free in alteration during metamorphism and deposited in the form of quartz veins cutting the sericite schists. The Bessemer granite yielded more easily to processes of metamorphism than the granitic rocks of the Carolina gneiss.

PEGMATITE.

Pegmatite is abundant in the area of Archean rocks, and a few small deposits have been observed in other formations. The rock is variant in composition but normally is composed chiefly of feldspar and quartz, with or without mica and other minerals. In some varieties feldspar is practically absent, and the pegmatite is composed chiefly of quartz and mica. Pegmatite is allied to granite in composition but is of more varied and much coarser texture. In some of it individual minerals may measure more than a foot across.

The pegmatite occurs in sheets, lenses, and irregular masses ranging in thickness from a few inches to many yards and attaining half a mile in length. These masses may follow the bedding or the schistosity of the country rock or may cut across them at various angles. Most of the deposits are too small to be shown on any ordinary geologic map, but some of the larger ones and those of special interest because of their mineral associations have been mapped and will be shown in the folios describing this district, which are now in preparation. A few of the pegmatites have a pronounced schistose structure, but most of them are massive. Some of the pegmatites are probably of Archean age, but the majority are probably younger and are genetically connected with post-Cambrian granite intrusions, especially with the Whiteside granite. The mineral composition and variations of the pegmatites are given in considerable detail in the descriptions of the mines and prospects (pp. 135–146).

WHITESIDE GRANITE.

Distribution.—The granite of this region that has been correlated with the Whiteside granite of the Pisgah and other quadrangles to the west covers large areas of the Kings Mountain district. It has been observed at many places in the region between this district and the Pisgah quadrangle, and it has been mapped in the Morganton, Mount Mitchell, and Saluda quadrangles of North Carolina. The name is taken from Whiteside Mountain, in the Cowee quadrangle, west of the Pisgah quadrangle, where the granite crops out in tremendous cliffs. Because of its relations to the associated rocks, the Whiteside granite is considered to be of later age than Cambrian, and possibly it was intruded during the mountain-building period at the end of the Carboniferous.

Character.—The granite is composed chiefly of orthoclase, microcline, and oligoclase feldspar, quartz, muscovite and biotite mica, and such accessory minerals as magnetite, apatite, and zircon. Minerals of secondary development are garnet, epidote or zoisite, chlorite, and kaolinite. The feldspars are the predominant minerals and the micas the most variable in abundance. Muscovite is more plentiful than biotite. Garnet is plentiful in some parts of the granite, especially those which have received a schistose structure through metamorphic processes; in some of these the garnets measure a tenth of an inch in diameter.

The granite is generally of light-gray color, and those varieties in which biotite is scarce are nearly white. Most of it has a medium to fine grain, especially in the smaller masses. In some places it shows a porphyritic texture, as in parts of the mass in the northeast corner of the Lincolnton quadrangle. The porphyritic forms appear much coarser grained because of the considerable size of the feldspar phenocrysts. Variations occur in different parts of the same bodies of the granite, some showing porphyritic phases and others the more even grain characteristic of the greater part of the Whiteside granite.

The Whiteside granite has yielded to metamorphism to varying degrees. In many places there is a gradation from typical granite in the interior of a mass to strongly schistose or gneissic granite at the border. The bulk of the granite shows only moderate metamorphism.

In places the Whiteside granite exhibits flow banding marked by an arrangement of minerals in roughly parallel layers. This structure may have developed in two ways, either during the intrusion of the granite magma in which a partial segregation of the minerals had already taken place or by the mashing and flowing under pressure of granite which contained partly absorbed masses of other rocks. These processes have yielded rocks characterized by discontinuous irregular wavy bands of different minerals. The flow structure may be present in one part of a granite mass and absent in another a few feet distant.

Relations.—The Whiteside granite is intrusive into all the rocks with which it is in contact in these quadrangles except the Triassic diabase dikes. Intrusive relations are shown by the doming action of batholiths, from the borders of which the layers of gneiss dip away at various angles, by the inclusion of masses of the gneisses with which it is in contact, by the occurrence of dikes both conformable with and cutting across the layers of the inclosing gneisses, and by the relations of the granite to pegmatite that cuts other rocks.

The best illustration of batholithic intrusion is around Cherryville, where the Whiteside granite has invaded the gneiss as a great batholith and also as sills, especially to the southwest of the main mass.

The interlayered masses of gneiss and granite dip away from the main mass of granite to the south and southwest.

Sill-like dikes of the granite are abundant in the gneisses, especially near the batholiths, and in some places these dikes branch out or turn across the schistosity, cutting from one layer to another.

Irregular bodies of pegmatites occur in the granite and extend from it out into the surrounding rocks. The texture of these pegmatites varies from extremely coarse to that of a coarse granite. In places pegmatite appears to grade into the granite. The invariable association of the pegmatite with the granite and the gradation of the one into the other show that they are related in origin. In places the gneisses and schists have been intruded by dike after dike of granite and injected by so much pegmatite that, with the unsatisfactory outcrops in this region, it is impossible to determine which rock is the more abundant, the original gneiss or the granite and allied pegmatite.

Inclusions.—Within the Whiteside granite are included numerous masses of the rock intruded by it, but this relation is best exhibited where the hornblendic rocks of the Roan gneiss are intruded by the granite, especially in a large area 3 to 5 miles south of Cherryville, in the Lincolnton quadrangle. Many of the inclusions have been more or less absorbed by the granite magma, which they have changed in composition. The absorption of the schists of the Carolina gneiss has yielded streaks of highly micaceous granite grading into highly micaceous schist. When they were intruded the hornblendic formations were broken up into more blocklike bodies, which floated out into the granite magma. Such inclusions were more or less dissolved by the inclosing magma, so that the magma became more basic near them. Thus the composition of the granite may be changed over considerable areas, and gradations occur from diorite inclusions seemingly to quartz diorite, to hornblende-biotite granite, to granite rich in biotite, and to the normal Whiteside granite.

THE TIN DEPOSITS.

GENERAL FEATURES.

Distribution.—The presence of cassiterite, oxide of tin, at many places in the Kings Mountain and Lincolnton quadrangles, at one place near Gaffney, in the Gaffney quadrangle, and at one locality in the Gastonia quadrangle has led to much prospecting and to attempts at mining. In at least one place—the Ross mine, near Gaffney—placer mining was temporarily done at considerable profit. Several prospects have also been opened in the Lincolnton and Gastonia quadrangles north and northeast of the Kings Mountain quadrangle.

Practically all the work on cassiterite-bearing veins has been done at a loss, but this work has not been sufficiently conclusive to prove or disprove the value of some of the deposits.

The cassiterite deposits have been found in a belt extending from a point 2 miles northeast of Grover, about parallel with the general trend of the rock formations, through the town of Kings Mountain and northeastward to Beaverdam Creek, 6 miles from Lincolnton. So far as known the Ross tin mine, near Gaffney, is on an isolated deposit, but this lies in about the same belt of rock formations as those between Grover and Kings Mountain.

Inclosing rocks.—The tin deposits occur in pegmatite masses within Archean rocks, either the Roan gneiss or the Carolina gneiss along or near its contact with the Roan gneiss. The belt of deposits lies within a mile northwest of the belt of Cambrian (?) rocks in the Gaffney and Kings Mountain quadrangles. To the north, in the Lincolnton quadrangle, the tin deposits diverge more widely from the Cambrian (?) rocks, but in the Gastonia quadrangle, east of the Lincolnton, they approach those rocks again.

The rocks inclosing the pegmatite are hornblende schist, hornblende gneiss, diorite, mica schist, and mica gneiss, with or without accessory garnet and kyanite. These formations have steep dips along the tin belt.

Occurrence of pegmatite.—The pegmatite occurs in sheets and lens-shaped bodies cutting the gneisses and schists. Some of the pegmatite masses are conformable with the structure of the inclosing schists, but others cut across the schist layers with various dips and strikes. Inclosed in the same formations are many other pegmatite bodies which are more or less similar to those bearing cassiterite but in which this mineral has not yet been found.

There are great variations in mode of occurrence and character of the pegmatites of the tin belt, including those which contain cassiterite. The masses range from less than an inch to 100 feet in width and from a few inches to probably more than half a mile in length. Some are only little longer than they are wide; others occur as large thin sheets. Some of the pegmatites occur in more or less parallel position, others in a belt with overlapping ends or in line with one another, and others lying at various angles with one another. The occurrence, where exposures are poor, of several bodies of pegmatite lying parallel and a few feet apart has misled some observers in estimating the width of some of the deposits. The pegmatite masses may fork or have connecting branches. They may turn, swell, pinch out abruptly or taper down at the ends. These variations may occur in different planes. Some of the pegmatites are more regular than others and hold one direction of strike or dip for considerable distances. The greatest irregularities occur in those bodies which cut across the schists or gneisses, or in those which branch from deposits otherwise conformable with the schistosity of the inclosing rock.

Origin of pegmatite.—The relations of the pegmatites to the inclosing rocks are chiefly those of intrusives, modified in some places by the action of solutions or gases. It is possible that some of the pegmatites have been deposited from aqueo-igneous solutions, but probably the majority, especially of the larger massive deposits, were mass intrusions. To which class many of the different pegmatites belong is a matter of uncertainty. Both types are supposed to be the products of granitic magmas that contained an excess of water and possibly gases and other mineralizing agents under conditions of heat and pressure. In the crystallization of a granite magma water is expelled and in part accumulates in the portion of the magma that remains unsolidified. This remaining magma accordingly becomes more fluid and may be regarded as an extremely hot concentrated aqueous solution. The expulsion of this liquid magma or solution into surrounding rocks gives rise to masses of pegmatite, which grade between typical dikes and typical veins.

Composition of pegmatite.—The pegmatites of the tin belt, including those that carry cassiterite, are somewhat diverse in composition. Some are composed of the usual minerals, feldspar, quartz, and mica, without appreciable quantities of other constituents. Others carry spodumene and cassiterite. Cassiterite occurs both in pegmatites which contain spodumene and in those which do not. The other minerals observed in the cassiterite-bearing pegmatites are few and not important. Such minerals as wolframite and arsenopyrite, which are associated with tin ore in other regions, appear to be absent here. The variations in composition consist chiefly in variations in the proportion of the different minerals present. In some deposits feldspar predominates; in others quartz; in some mica is absent and in others abundant.

Great irregularities occur in the distribution of the minerals. Quartz is segregated into large separate masses in some deposits and mixed through the rock in coarse grains in others. Cassiterite in small deposits occurs in scattered grains through one part of the pegmatite body and is absent a number of feet distant in another part. In some of the large pegmatite bodies the cassiterite is irregularly scattered through large masses of the rock, and in others it occurs more or less irregularly concentrated along one wall of the pegmatite as a smaller vein but connected with the main mass. In some of the pegmatites rich in cassiterite feldspar is only sparingly present if at all. This kind of deposit, then, has the nature of greisen and has been observed as lenses or streaks in larger bodies of pegmatite and along the contacts of such bodies with the inclosing rocks.

The cassiterite appears to have been one of the first minerals in the pegmatite to crystallize. Its boundaries are sharp, although crystal outlines are rather rare. Nowhere has a gradation between cassiterite and quartz or feldspar been observed, as there would be if the cassiterite had been introduced by metamorphism after the pegmatite was formed; nor are there inclusions of other minerals in the cassiterite. Accordingly it seems clear that the cassiterite was an original constituent of the pegmatite—a view which has already been stated by Graton. In some places the concentration of the cassiterite in greisen along the pegmatite border indicates metamorphic action, during which there were mutual reactions between the dike and the wall rock. The cassiterite, the earliest mineral to crystallize, formed first near the wall. The reaction of wall rock and dike is also evident by the unusual coarseness of the mica schist of the wall in many places.

Age of tin deposits.—The rocks in the tin belt are of two classes—(1) the gneisses, etc., of Archean age, and (2) the granites, pegmatites, and quartz veins, which cut the Archean rocks. The Archean rocks are greatly altered by deformation, but the younger rocks show little or no alteration. The Whiteside granite was locally rendered schistose but for large areas is massive and unaltered. It is therefore concluded that most of that granite is younger than the mountain-building movements which deformed and altered this entire region. This conclusion assigns to the Whiteside granite a late Carboniferous age. Similar reasoning assigns a late Carboniferous or post-Carboniferous age to the pegmatites and quartz veins.

It seems probable that granite, pegmatites, and quartz veins form a cycle, the granite having invaded the Archean rocks nearly at the end of the Carboniferous period, the pegmatites representing a later stage of intrusion, partly in mass and partly by permeating solutions, and the veins being the final products of the cooling magma. The general distribution of the rocks favors this view, for the tin-bearing pegmatites are not in the granite but are near its general southeast margin, while the quartz veins, more or less mineralized, occupy a general belt southeast of and farther away from the granite.

MINES AND PROSPECTS.

GAFFNEY QUADRANGLE.

ROSS MINE.

The Ross tin mine is about 1½ miles northeast of Gaffney, on the northwest side of a small hollow that drains northeastward into a tributary of Providence Branch. The work consists of many open cuts and placer washings, pits, and trenches, and a shaft more than 130 feet deep, with levels, all within a space about 600 feet long from northeast to southwest and 100 feet wide. Placer mining has been done on the lower part of the slope, where water was available, and material obtained above this place has been carted down to the sluice boxes. In this way the greater part of the hill slope from a point near the shaft northeastward to the branch, a distance of about 400 feet, has been worked over.

The shaft and underground workings were not accessible at the time of visit, but portions of the vein were exposed in shallow workings, and these, with descriptions by Sloan and Graton, furnish material for the notes here given. A crosscut was driven from the shaft northwest to the vein on the 63-foot level, and winzes were sunk on the vein from this level to the 90-foot level and there connected by a drift. The shaft cuts the vein at a depth of nearly 100 feet.

The placer material consisted both of weathered vein material approximately in place and of hillside débris derived from the vein. Where the loose material only was washed, the work was carried only a foot or two deep, but where the weathered outcrop of the vein constituted the placer material, excavation was carried to depths of more than 10 feet.

The country rock consists of interlayered hornblende schist and fine biotite gneiss, probably belonging to the Roan gneiss. These rocks strike about northeast, and dips were measured ranging from 25° SE. in the branch to 60° SE. in the mine workings. Along the stream the rocks are only slightly altered, but in the underground workings the saprolite was found to extend to depths greater than 60 feet, passing gradually into less altered rock. From the lower workings hard, fresh wall rock was brought up but the vein material is partly altered to the bottom of the mine. The wall rock on the dump consists of rather coarse hornblende schist and garnetiferous biotite gneiss. The pegmatite in the upper workings is decomposed by kaolinization of the feldspars. Specimens examined from the lower workings are hard, compact, and schistose and contain an abundance of compact fine sericite or pinite and a fibrous mineral like sillimanite. Under the microscope were observed partly sericitized orthoclase, oligoclase, muscovite and sericite, sillimanite, cassiterite, a prismatic mineral that is probably staurolite, and iron ore.

In the upper workings the streaks of hornblende schist have weathered to dark yellowish-brown saprolite and the mica and garnet gneiss to dark-grayish saprolite. The pegmatite is represented by masses of white kaolin and a little intermixed quartz with some mica.

The cassiterite-bearing pegmatite occurs as a series of irregular sheets and lenses approximately conformable with the inclosing gneiss and schists—that is, it has a northeast strike and a dip of

50°–60° SE. The train of pegmatite bodies, or "vein," is from 1 to nearly 10 feet wide, and the individual masses measure from less than an inch to 4 feet in width. The tin content varies widely. Graton mentions a 100-pound sample taken across a pegmatite body on the 75-foot level which contained 9 pounds of cassiterite, or about 6.5 per cent of metallic tin.

Most of the ore taken from the Ross mine was decomposed and soft and could be readily concentrated in sluice boxes. The ore taken from the lowest workings, however, was hard and would require crushing before concentration. The concentrates obtained have generally averaged over 65 per cent metallic tin. Sloan states that the total shipments of cassiterite concentrates from the Ross mine to 1906 amounted to about 130 tons. The shaft was sunk to its present depth in 1907. Since that time only a little surface testing with some sluicing has been done, resulting in a production of a few thousand pounds of concentrates.

KINGS MOUNTAIN QUADRANGLE.

LOCALITIES.

Twenty or more places in the Kings Mountain quadrangle have been prospected for cassiterite. During 1907 the Blue Ridge Tin Corporation worked in the town of Kings Mountain and at several places southwest of the town along a line of prospects opened by Ledoux & Co. in 1888 and 1889. A promising prospect on the Faires place was tested by Capt. S. S. Ross and others, of Gaffney. Named in order from the north border of the Kings Mountain quadrangle to the south and southwest some of the mines and prospects are: The old Blue Ridge Tin Corporation mine, on the west side of the railroad tracks in the town of Kings Mountain; Mrs. Elizabeth Falls's prospect, two-thirds of a mile south of the town; the Faires prospect, eight-tenths of a mile west of south of the town; prospects tested by the American Tin Plate Co., adjoining the Faires prospect on the southwest; the Mike Plonk prospect, 1¼ miles southwest of the town; a series of openings made by Ledoux & Co., beginning 1½ miles southwest of the town and extending one-third of a mile southwest along a ridge; an old prospect opened by Ledoux & Co., 1¾ miles southwest of the town; the principal workings of the Blue Ridge Tin Corporation, 2 to 2⅓ miles southwest of the town, consisting of two shafts, drifts, and some placer work; three prospects of the Blue Ridge Tin Corporation, beginning west of the placer ground and within half a mile to the southwest; other prospects to the southwest and one two-thirds of a mile southeast of Crocker opened by Capt. Ross in 1903. Still other prospects farther southwest are reported but were not examined. Float tin has been found at other places in the town of Kings Mountain and along the belt southwest of the town.

KINGS MOUNTAIN MINE.

At the Kings Mountain mine of the Blue Ridge Tin Corporation three shafts were sunk from 50 to 75 feet deep and some drifts run from them. Two of the shafts were about 50 feet apart and near the railroad tracks. A mill for treating the ore was erected close by. The third shaft is about 150 feet west of the mill and on a different "vein." The workings were not available for examination at the time of visit and little could be learned of the result of the operations. Rich ore was found in pegmatite débris on the surface and similar rich ore was reported from parts of the underground workings.

The country rock is strongly folded coarse mica schist with a body of similarly folded hornblende schist less than 100 feet to the south. The strike of the schistosity of these rocks is north to west of north and the dip about vertical, but the contact of the two formations runs as a whole nearly east, although jagged in detail. This is due to rather close folding with a strong northward pitch in the folds. The cassiterite-bearing pegmatites are nearly conformable with the schistosity of the inclosing rocks, and the ore shoots would probably be found to pitch northward in conformity with these folds. The pegmatites are variable in width, ranging from less than a foot to several feet as exposed near the collar of the western shaft. Most of the pegmatite, especially that rich in feldspar, is weathered and soft in the upper part of the workings, but some of the greisenlike ore rich in cassiterite is but little altered, even at the surface.

Cassiterite-bearing pegmatite crops out about 150 yards southeast of this mine in the gutter of one of the side streets of Kings Mountain and is reported to have been found in a well about 300 yards farther south. A number of loose cassiterite crystals were found one-third of a mile west of the railroad on both sides of the street leading toward Shelby.

FALLS PROSPECT.

The Falls prospect is on the east side of a small hollow in the south part of the town of Kings Mountain. It was tested a number of years ago by trenching along the hillside and sinking some shafts. Large pegmatite bodies were exposed in the hillside workings, but little cassiterite was found in them. A shoot of rich greisen was found in a shaft on top of the hill east of the trenches. Here the cassiterite-bearing greisen formed a pocket or shoot about 2 feet wide in a body of pegmatite about 8 feet wide. The pegmatite is inclosed between chlorite schist on the northwest and mica schist on the southeast. A ledge of tourmaline-quartz rock crops out in the branch about 75 yards southeast of the place where the tin lead crosses it. This ledge is composed of gray to smoky quartz penetrated by a large number of long, thin crystals of black tourmaline. In some parts the tourmaline composes about half of the vein.

FAIRES PROSPECT.

Development work on the Faires property, a quarter of a mile southwest of the Falls prospect, consists of several pits and a 40-foot shaft with 200 feet of drifts, now badly caved in. A 10-foot pit at a place where rich float was found exposed a cassiterite-bearing pegmatite dike 3 feet wide striking N. 30° E. with a high northwest dip. The vein was cut on the 40-foot level by a crosscut from the shaft on the southeast. Here the pegmatite, it was reported, is about 3 feet thick and carries cassiterite. A drift to the northeast showed the pegmatite to be wider and to carry more cassiterite. Another pegmatite dike was prospected 33 feet southeast of this "vein" but did not carry cassiterite. The pegmatite from the underground workings is badly decomposed, most of the feldspar being kaolinized. The parts richest in cassiterite contain less feldspar and are harder. Some of the ore taken out was very rich, and in one section exposed the rock was estimated to carry about 10 per cent cassiterite. The country rock is hornblende schist, badly decomposed. A tourmaline-quartz vein is inclosed in the schist a few yards southeast of the pegmatite.

Other prospects were opened southwest of the main workings, on other outcrops of pegmatite. Cassiterite was found in some of these also, and in one of the exposures appears to be in promising quantity. About 300 or 400 yards southwest of the main deposit a large body of spodumene-bearing pegmatite over 40 feet wide crops out prominently in the north side of a small valley. No cassiterite was observed in this rock. Similar outcrops of spodumene-bearing pegmatite occur within half a mile to the southwest, but most of them lie northwest of the belt in which tin ore has been found.

PLONK PROSPECT.

On the Plonk property a long trench was cut across the formations, exposing both spodumene pegmatite and cassiterite-bearing pegmatite inclosed in hornblende schist. The formations strike N. 35° E. and dip 75° NW.

OLD LEDOUX PROSPECTS.

Considerable prospecting has been done along the ridge adjoining and to the southwest of the Plonk property, first by Ledoux & Co. in 1888 and 1889 and later by the Blue Ridge Tin Corporation. At the northeast is an old crosscut trench, where little is to be seen at present. Next is a trench about 200 feet long and 5 to 20 feet deep along the east contact of a large pegmatite. At the surface the contact strikes N. 25° E. and dips 80° NW., but at a depth of 20 feet the dip is 60° NW. Coarse garnetiferous mica schist forms the footwall of the pegmatite. Cassiterite was found in a greisen-like phase of the pegmatite along the footwall. The cassiterite-bearing portion is from 1 to 3 feet wide and is rich in some places and poor in others. It is reported that a vertical diamond-drill hole bored over 100 feet west of the " vein " cut 5 feet of ore at a depth of 275 feet. The pegmatite dike at this place is probably at least 25 feet wide. To the northwest are other large masses of pegmatite separated from one another by several feet of schist. These bodies do not crop out distinctly, and pegmatite bowlders have rolled between them, giving an appearance of one large deposit several hundred feet wide. Some of them carry considerable spodumene but apparently no cassiterite. The cassiterite-bearing mass is inclosed in mica schist, but most of the other masses are in hornblende schist.

About 50 yards southwest of the long trench a shaft 85 feet deep, called No. 1 by the Blue Ridge Tin Corporation, was sunk near a pit where good ore had been found. A 60-foot crosscut from the shaft cut three " veins," one of which carries cassiterite. These pegmatite veins are in interlaminated hornblende schist and garnetiferous mica schist. Further southwest is a trench 100 feet long and 3 to 12 feet deep on a contact similar to that just described. This contact strikes about N. 25° E. and dips 80° W. Cassiterite was found in part of this trench, and some of the material was promising-looking ore. A short distance to the southwest two shafts have been sunk, one on spodumene pegmatite. Cassiterite was reported in both of these shafts.

Near the end of the ridge a trench was made along the southeast contact of another large body of spodumene-bearing pegmatite, which carries cassiterite along the southeast wall. The wall rock on this side is chloritic mica schist.

About 200 yards west of this trench, on a knoll across a small valley, is another old shaft, 60 feet deep, in a large pegmatite dike carrying spodumene. A little cassiterite was found at this place and also at another pegmatite outcrop opened by two pits about 200 yards southwest. The inclosing rock is hornblende schist at both of these prospects.

BLUE RIDGE TIN CORPORATION MAIN WORKS.

At the northeast end of the outcrops on the property of the Blue Ridge Tin Corporation a shaft 80 feet deep (No. 4) was sunk, with a 60-foot drift to the southwest on the 60-foot level. A 20-foot prospect shaft was sunk south of the main shaft. Two "veins" were found—one in the 20-foot shaft and the other along the northwest side of the drift on the 60-foot level. The material of these "veins" consists of schistose greisen-like pegmatite and is reported to be badly crushed in the underground workings.

About 200 yards to the southwest is shaft No. 5, 130 feet deep. Underground workings cut two "veins" carrying cassiterite. One of these veins that crops out 15 feet southeast of the shaft was cut a few feet from the shaft in a crosscut to the southeast on the 85-foot level and in the shaft near the bottom. This "vein" is said to contain fine-grained ore at the surface but coarser ore underground. The outcrop of the other vein was not found, but the ore was cut in the crosscut on the 85-foot level. It is said to have been coarse-grained and rich ore. Another cassiterite-bearing pegmatite body was opened by a 25-foot shaft about 60 yards west of the main shaft.

A large spodumene pegmatite mass about 15 feet wide crops out between shafts No. 4 and No. 5. Débris of cassiterite-bearing pegmatite or greisen was found near this mass, and a little cassiterite was observed in the spodumene-bearing part.

The country rock at these workings consists of interlaminated hornblende schist and bluish mica schist having a northeast strike and high to nearly vertical northwest dip. The "veins" seem to be at least approximately conformable with the inclosing schist.

Placer deposits have been worked in the bottom land along the valley southwest and south of the mine. The ground favorable for this work is from 50 to 100 yards wide at the lower end and tapers northwestward to shoals where the tin lead crosses the stream. It has a length of over 200 yards. Water is available, and parts of the placer ground are reported to have been tested with encouraging results. At one time some of the alluvial material was hauled up an incline track to a concentrating mill on the hillside, but although several thousand pounds of concentrates were washed out the work was not profitable with such equipment.

On the hill on the southwest side of this same valley a 25-foot shaft was sunk and a 10-foot crosscut run. A body of spodumene pegmatite, 5 feet wide, was found inclosed in hornblende and chlorite schist. A little cassiterite is reported to have been taken out. In two prospects within half a mile southwest similar spodumene-bearing pegmatite masses were opened. They are in hornblende and chlorite schist. Cassiterite is reported to have been found in both. A mass of tourmaline-quartz rock occurs about 10 feet southeast of one of these pegmatite masses.

ROSS PROSPECT.

At the old prospect two-thirds of a mile southeast of Crocker, opened by Capt. S. S. Ross in 1903, a pit was sunk on the southeast side of a body of pegmatite about 20 feet wide. This pegmatite is said to contain considerable cassiterite in a streak several inches thick along the southeast wall but only a few scattered grains within the mass. Bluish mica schist forms the wall rock, but 45 feet to the southeast there is a belt of hornblende schist. A vein of tourmaline quartz is inclosed in the hornblende schist about 50 yards southeast of the pegmatite.

LINCOLNTON QUADRANGLE.

PROSPECTS ALONG CHESTNUT RIDGE.

The Mauney Park prospect is on the south side of a small valley cutting eastward across Chestnut Ridge, about 1 mile north of the north edge of the town of Kings Mountain. The deposit is near some springs which have been walled up and around which the grounds have been cleared as a park. It was discovered by the presence of a number of boulders of greisen, rich in cassiterite and weighing from 30 to 150 pounds each, loose in the surface soil. A small amount of prospecting was done during the "tin excitement" of 1904. This work consisted in clearing out undergrowth and digging pits and a crosscut trench. The pits are on the north side of a small ridge pitching east and the trench is on the south side of the ridge, 65 yards due south of the pits.

The country rock consists of kyanite-mica schist and gneiss with a narrow belt of hornblende schist close to the tin-bearing pegmatite. The schists strike north and have a vertical dip, and the pegmatite is approximately conformable with them. The pegmatite exposed in one of the pits is nearly 8 feet wide. Of this width 2 feet along the west wall consists of cassiterite-bearing greisen. The remaining 6 feet of pegmatite is highly feldspathic and carries but little cassiterite. This portion of the dike is soft and crumbling owing to the kaolinization of the feldspar. The feldspar-free greisen portion is fresh and hard and shows a few iron oxide and clay stains. Part of the greisen is rather fine-grained, and part is coarse containing muscovite crystals an inch across. In places at least 10 per cent of the greisen is cassiterite, some of which occurs in crystals an inch long and half an inch thick.

Pegmatite was cut in the trench on the south side of the ridge, apparently in direct line with the cassiterite-bearing pegmatite on the north side. No cassiterite was observed at this place, however. From 20 to 30 yards east of this an outcrop of spodumene-bearing pegmatite extends in a west of north direction across the ridge. No cassiterite was seen in the prospects opened on this spodumene pegmatite.

Cassiterite-bearing greisen is found in a cultivated field a quarter of a mile due north of the Mauney Park prospect, on the west side of Chestnut Ridge. Boulders of this rock have been plowed up, but no prospect work has been done.

The Horton shaft, 122 feet deep, was sunk in 1893 on the east side of Chestnut Ridge half a mile northeast of the Mauney Park prospect by residents of Kings Mountain. Crosscutting was started, and cassiterite-bearing pegmatite is reported to have been found. This prospect is not in line with the Mauney Park lead but is in line with other prospects on the east side of Chestnut Ridge and east of Long Creek Church. At one of these, on the land of J. J. Ormond, a quarter of a mile east of the north end of Chestnut Ridge, cassiterite-bearing greisen was found in surface boulders and in a prospect shaft. A little cassiterite has been found between the Horton shaft and the Ormond prospect along the east side of Chestnut Ridge.

ORMOND-CARR PROSPECT.

The Ormond-Carr prospect is a quarter of a mile east of Long Creek Church. A shallow shaft and a few pits were made in a north-south direction along an outcrop of pegmatite. The country rock is hornblende schist of the Roan gneiss. A narrow belt of staurolite schist crops outs a few yards east of the deposit. The formations strike about north and have a high westerly dip, and the pegmatite is approximately conformable with them. The pegmatite exposed is from 5 to 8 feet wide and carries cassiterite in places.

HOVIS PROSPECT.

The M. V. Hovis prospect is 1⅔ miles N. 12° E. of Long Creek Church. Cassiterite is found in loose crystals and in small boulders of greisen scattered over a field and along the public road. A 35-foot prospect shaft was sunk a few yards west of the road, and decomposed pegmatite was encountered in it, but no cassiterite was seen at the time of examination. The country rock is evidently chiefly hornblendic schist weathered to a dark-brown soil.

RAMSEUR MILL PROSPECT.

The Ramseur Mill prospect is about a third of a mile east of north of the Hovis prospect, or nearly 2 miles east of north of Long Creek Church. A shaft and a trench were made here during the first tin excitement, and some very promising cassiterite-bearing greisen was thrown out. The country rock is hornblende schist with varied strike and dip. The attitude of the pegmatite is not plainly evident, but the trench made along the northeast contact showed this to have a N. 30° W. strike. The pegmatite body is large, at least 15 feet wide, and crops out through a distance of about 75 feet. The cassiterite was found in a greisen streak 1 to 2 feet thick along the northeast wall.

JONES MINE.

The Jones mine is about 3½ miles N. 30° W. of Bessemer City. It was first prospected in about 1892 or 1893, but the principal work was done between 1903 and 1904. The following description is partly taken from a report by Graton,[1] supplemented by notes of D. B. Sterrett. The early workings consisted of a shallow shaft and some pits on a pegmatite vein striking north of west with a nearly vertical dip. At one place this vein was 2½ feet wide and very rich in cassiterite. About 70 feet west it contained only a small quantity of cassiterite, and 70 feet still farther west cassiterite was absent.

Later work was rather extensive. Shafts and trenches were made along the vein first opened through a distance of about 200 feet. A shaft 175 feet deep was sunk about 150 feet N. 70° W. from the west end of the workings along this vein, and still another shaft 150 yards west of this. A second pegmatite vein 100 yards south of the first one was opened by prospect pits through a distance of about 100 yards in a northwesterly direction. In all, about 500 feet of underground work is reported to have been done. A small amount of placer mining was carried on in the branch east of the deposit. A mill was erected at the mine, and a carload of concentrates is reported to have been shipped.

The deposits occur near the contact of interlaminated hornblende schist of the Roan gneiss and mica gneiss of the Carolina gneiss. The strike of these formations ranges from east of north on the east side of the deposit to nearly west near the middle of the workings and northwest near the west workings. The dip ranges from 50° N. to nearly vertical. The first vein opened cuts across the bedding of the country rock, having a north of west strike and a nearly vertical dip. Along the contact of this pegmatite the mica gneiss contains a quantity of small black tourmaline crystals and needles. Pegmatite also occurs in small offshoots from the larger bodies and in lenses and stringers near them.

The pegmatite mass is variable in character. In some places it has about a normal mineral composition. In others the feldspar is subordinate, or almost absent, and cassiterite may or may not be present.

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[1] Graton, L. C., Reconnaissance of some gold and tin deposits of the southern Appalachians: U. S. Geol. Survey Bull. 293, pp. 40–48, 1906.

Some of the pegmatite from the 175-foot shaft contains spodumene. Where cassiterite is plentiful the pegmatite does not carry so much feldspar, and in places where there is more than 10 per cent of cassiterite feldspar is practically absent.

Some of the richest ore was found in the vein first opened. A small sample of ore from the earlier workings yielded cassiterite equal to about 5 per cent metallic tin when crushed and panned. Graton states that the average of all the pegmatite broken in the mine is said to have been about 0.7 per cent of metallic tin.

STROUP AND RAYFIELD PROSPECTS.

Prospects were opened in 1904 along the boundary line between the places of Nora Rayfield and John Stroup, 2½ miles S. 60° W. of Landers Chapel, but these pits are now filled up. The country rock is hornblende schist, and a belt of kyanite gneiss lies a few yards west of the tin deposits. Cassiterite-bearing pegmatite was found in the prospects, but only a few pieces of this ore, of medium grade, were left on the surface at the time of examination.

HASTINGS PROSPECT.

The H. P. Hastings prospect is about half a mile northeast of the Stroup and Rayfield prospects, or 2 miles S. 65° W. of Landers Chapel. It was opened by a 14-foot shaft and a crosscut trench. Cassiterite-bearing pegmatite was found on the surface for a distance of about 100 feet in a northeasterly direction. The country rock consists of interbedded hornblende schist and kyanitic mica gneiss, which strike northeast and have a high northwest dip. The pegmatite is approximately conformable with the bedding of the inclosing rock. The ore is medium grained and carries a large percentage of quartz, a little feldspar, mica, and fine cassiterite.

BALDWIN AND ALLEN PROSPECTS.

The prospects of J. Baldwin and J. R. Allen are a third of a mile northwest of the Hastings prospect, or 2 miles S. 73° W. of Landers Chapel. They are on opposite sides of the public road, the Baldwin prospect about 80 yards southwest of the road and the Allen prospect about 150 yards N. 55° E. from the Baldwin prospect. A 45-foot shaft was sunk at the Baldwin prospect, and a few blasts were made in the outcrop. Two pits, now partly filled up, were made at the Allen prospect.

The country rock is diorite and hornblende schist of the Roan gneiss. The schist strikes northeast and has a high northwest dip. The prospects are in lenticular-shaped outcrops of spodumene-bearing pegmatite which forms a small oval knoll. These pegmatite outcrops are 10 to 20 feet wide and 50 feet or more long. Some of them are in line with one another, and others overlap at the ends. In texture the pegmatite is about medium-grained, the feldspar crystals ranging from less than 1 inch to 4 inches in thickness and the spodumene crystals being 1 or 2 inches long. The spodumene is mostly opaque and gray, but a few crystals with transparent yellowish-green portions were observed. The mica of the pegmatite is yellowish green and occurs chiefly in small crystals half an inch or less in diameter. The cassiterite is present in rather small grains and crystals scattered through parts of the pegmatite. Pieces of medium-grade ore, 10 to 12 inches across, were left on the dumps. Cassiterite was not found in all the outcrops of spodumene pegmatite.

Four ledges of decomposed spodumene pegmatite are exposed in a space of 100 feet along the road and about 100 yards east of the tin-bearing lead, but no cassiterite was seen in them.

LOUISIANA CLAYS.

By George Charlton Matson.

INTRODUCTION.

The facts that Louisiana possesses a large amount of good timber and is primarily an agricultural State have made it unnecessary to develop her clay resources for the purpose of obtaining structural materials, except in the vicinity of some of the larger cities. Nevertheless Louisiana has held high rank in the output of clay products among the States bordering on the Gulf of Mexico, though in 1915 she ranked thirty-third among all the States in the Union, producing a little less than 0.25 per cent of the total value of the clay products of the country. The increase in the value of timber, together with the rapid growth of cities, will naturally lead to the production and consumption of larger quantities of building brick, terra cotta, tile, and other building materials, and it is therefore important to consider the possibilities of obtaining suitable clays for the manufacture of these materials. For this purpose samples of Louisiana clays were collected by the writer in 1912 and submitted to the Bureau of Standards for examination.

No attempt was made to collect samples from all the localities where clays occur, as this would require a large amount of time and be very expensive. Samples were obtained from the principal geologic formations of the State, and the distribution of these formations, together with the localities from which samples were taken, is shown on the accompanying map (Pl. V). However, most of these formations contain beds of sand or sandstone and will not furnish clays except in relatively small areas, distributed throughout the regions where the formations crop out. No attempt will be made to describe all the localities where clays suitable for the manufacture of clay products have been observed in Louisiana. Such localities are numerous throughout the areas of outcrop, but the descriptions will be confined to those localities where the samples were obtained. The sequence of the geologic formations is shown in the accompanying table, the youngest formation at the top and the successively older formations below. The oldest beds included in this table, belonging to the Cretaceous system, occur at the surface at very few places within the State. They are therefore of no importance as sources of clay.

Geologic formations that crop out in Louisiana.

System.	Series.	Group and formation.	Sample Nos.
Quaternary.	Recent.		2, 7, 10, 11, 12, 14, 15, 26.
	Pleistocene.		1, 8, 9, 13, 16, 17, 18, 19, 24, 25.
Tertiary.	Pliocene.	Citronelle formation.	3.
	Miocene.	Pascagoula clay.	22.[a]
	Oligocene.	Hattiesburg clay.	
		Catahoula sandstone.	
		Vicksburg limestone.	
	Eocene.	Fayette sandstone.	
		Jackson formation.	
		Claiborne group.: Yegua formation. St. Maurice formation.	5, 6, 20.
		Wilcox formation.	4, 21, 23.
		Midway formation.	
Cretaceous.			

[a] See also description of clay obtained 1 mile west of Lena, pp. 151-152. Ries, Heinrich, A report on Louisiana clay samples: Louisiana Exper. Sta., pt. 5, pp. 272-273, 1899.

GEOLOGIC DISTRIBUTION OF THE SAMPLES.

EOCENE SERIES.

MIDWAY FORMATION.

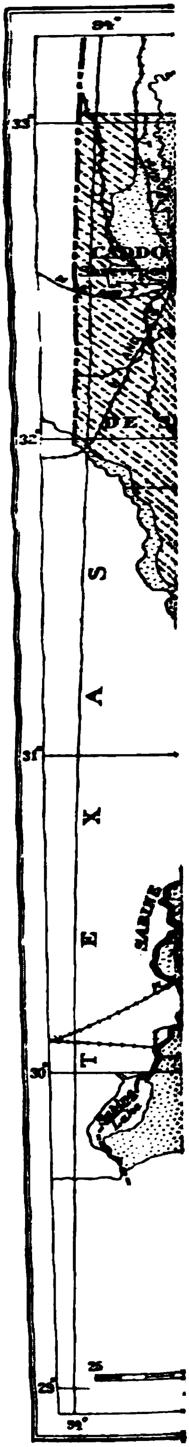
The Midway formation is exposed at only a few places in Louisiana, and the areas of outcrop are so small that the formation can not be an important source of clays for commercial use.

WILCOX FORMATION.

GENERAL FEATURES.

The Wilcox formation is at the surface over a large area in northwestern Louisiana, extending from the northern boundary of the State southward nearly to Many. This formation contains numerous clay beds that are distributed throughout the greater portion of the

U. S. GEOLOG



MAP SHOW

area in which it crops out. Associated with these clay beds are beds of sand and sandstone, and many of the clays are so sandy that it would be necessary to test those found at any particular locality in order to determine their value. A sample (No. 21) was collected near Mooringsport, in Caddo Parish, and two samples (Nos. 4 and 23) were collected near Mansfield, in De Soto Parish. The results of tests of these samples are given in the accompanying table. The sample from Mooringsport was one of the best clays collected in the State. This formation supplies some pottery clay in Mississippi,[1] but none of the samples obtained from Louisiana would be valuable for that purpose. It is possible, however, that clay suitable for the manufacture of pottery might be found at some localities where the Wilcox formation is exposed.

CLAY LOCALITIES.

Mansfield.—At Mansfield two samples were collected, one from the brickyard of B. Y. Wemple (No. 4 in table facing p. 156), and the other from exposures at the old nursery about 2 miles north of the town (No. 23).

Section in the clay pit at Wemple's brickyard, Mansfield.

	Ft.	In.
Yellow granular surface clay	4	0
Red clay mottled gray	4	0
Fine-grained ferruginous sandstone		4

Similar clays with thin partings of sand and sandstone have a thickness of about 25 feet near this locality. The sample was a composite of the yellow and mottled clays.

Section at the old nursery 2 miles north of Mansfield, on the east side of the Kansas City Southern Railway.

	Ft.	In.
Red sand		4-6
Micaceous clay containing some fine sand	15	0

The sample obtained here was taken in such a manner as to furnish a composite of the material underlying the surface sand.

Mooringsport.—On the old Richardson farm, 2 miles south of Mooringsport, on the west side of the Kansas City Southern Railway, two samples were collected—one, weighing about 50 pounds, from the upper bed of blue clay and one, weighing about 25 pounds, from the lower clay bed. These two samples were mixed, and the resulting composite sample (No. 21) was tested in the laboratory.

Section in clay pit on the old Richardson farm, Mooringsport.

	Feet.
Red granular clay containing some fine sand	2
Light-gray to blue micaceous clay with thin laminae of sand	6
Unexposed	4
Blue micaceous clay with thin laminae of sand	3

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[1] Logan, W. N., The pottery clays of Mississippi: Mississippi Geol. Survey Bull. 6, pp. 131-210, 1914.

CLAIBORNE GROUP.

GENERAL FEATURES.

The Yegua and St. Maurice formations of the Claiborne group occupy a wide area in north-central Louisiana, as shown on the accompanying map. Samples were collected from the St. Maurice formation at Natchitoches, Natchitoches Parish, and at Winnfield, Winn Parish. The sample procured at Ruston, in Lincoln Parish, probably came from the Yegua formation. The sample from Ruston (No. 5) was one of the few samples obtained in Louisiana that could be vitrified below a temperature of 1,230° C. The sample from Winnfield (No. 20) is of particular interest because, unlike most of the Louisiana clays, it burned to a buff color instead of red. Clays similar to those represented by these samples may be obtained at many localities where the Claiborne formations are exposed.

CLAY LOCALITIES.

Natchitoches.—At the brickyard of Hughes & Aaron, Natchitoches, the silt and clay shown in the subjoined section are mixed together in brickmaking, and a composite sample (No. 6) of the two was taken.

Section at the brickyard of Hughes & Aaron, Natchitoches.

	Ft.	in.
Gray silt	1	2
Gray massive clay	5	0

Ruston.—A sample (No. 5) was obtained near Ruston from the brown shale of the following section:

Section at Randolph's brickyard, half a mile west of Ruston.

	Feet.
Yellow clay containing a few nodules of limonite	3
Brown shale	6-15
Coarse sand	2+

Winnfield.—The sample collected near Winnfield (No. 20) was a composite of the light and dark shale.

Section at Gunn's brickyard, half a mile west of Winnfield.

	Ft.	in.
Gray sand	4	0
Red clay, slightly sandy	3	6
Light-gray shale, containing some yellow laminae	5	0
Dark-gray shale with some thin sand partings	4+	

JACKSON FORMATION AND FAYETTE SANDSTONE.

The Jackson formation and Fayette sandstone occupy a narrow belt extending from a point near Hornbeck eastward to Catahoula Parish. No samples were taken from this belt by the writer because the areas covered by these formations are small. Both of the formations will furnish some clays suitable for the manufacture of ordinary clay products, such as building brick, but the outcrop is narrow and at some distance from the larger cities, and it is probable that clays equally good or better could be obtained from other formations nearer the places where the products would be utilized.

A sample of shale from the Fayette sandstone in sec. 17, T. 3 N., R. 11 W., was examined by Ries,[1] in his laboratory at Cornell University. His tests included a mechanical analysis with the following results:

	Per cent.
Clay and fine silt	42.10
Very fine sand	57.25
	99.35

The amount of water required to temper the sample was 31 per cent, and the shrinkage on air drying was 11 per cent. The tensile strength of the air-dried briquet was good, amounting to 75 pounds per square inch. At cone 3 (about equivalent to a temperature of 1,208° C.) the clay had burned to a light red, with a total shrinkage of 12 per cent; and at cone 6 (about equivalent to a temperature of 1,269° C.) the color was brownish red and the total shrinkage was 14 per cent. Ries regards this clay as suitable for the manufacture of face brick when burned to a temperature of cone 6.

OLIGOCENE AND MIOCENE SERIES.

The Oligocene series includes the Vicksburg limestone, a marly formation occupying only a small area in Louisiana; the Catahoula sandstone, a formation that is predominantly sandy with some clay beds; and the Hattiesburg clay. The Miocene series contains a single formation, the Pascagoula clay. Clay beds are much more numerous in the Hattiesburg and Pascagoula clays than in the Catahoula sandstone and they are all of the same general type as that represented by sample 22, collected at Leesville, with the exception of local beds of calcareous clay. The Leesville sample was too plastic and shrank too much (see table facing p. 156) while being dried to be useful, but it could probably be utilized for the manufacture of ordinary clay products provided it was mixed with some sand.

Ries[2] tested a sample of clay obtained 1 mile west of Lena, probably from the Catahoula or the Fayette sandstone. It is described as a coarse-grained sandy clay that slaked very rapidly, required 21 per cent of water to temper, and had an air shrinkage of 10 per cent when dried. Its mechanical composition was as follows:

	Per cent.
Clay and fine silt	73.5
Very fine sand	26.3
	99.8

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[1] Ries, Heinrich, A report on Louisiana clay samples: Louisiana Exper. Sta., pt. 5, pp. 274-275, 1899.

[2] Idem, pp. 272-273.

The dry briquets had a tensile strength of 45 pounds to the square inch, which Ries thought would be sufficient for a brick clay, though a higher tensile strength was regarded as desirable. At cone 3 (about equivalent to a temperature of 1,208° C.) the clay showed signs of incipient fusion and was bright red. At cone 5 (about equivalent to 1,248° C.) the color had changed to a deep red and the product had begun to sinter, though even at this temperature the brick was not vitrified. It is probable that this sample more nearly represents the character of material that may be obtained from the Oligocene and Miocene formations than the sample collected near Leesville.

PLIOCENE SERIES.

CITRONELLE FORMATION.

The Citronelle formation occupies a broad area south of the outcrop of Pascagoula clay, and although it is predominantly sandy it contains a large number of thin beds and lenses of clay. The character of the clay beds found in this formation is shown by sample 3, which is suitable for the manufacture of common building brick.

PLEISTOCENE AND RECENT SERIES.

GENERAL FEATURES.

The Pleistocene and Recent deposits cover wide areas in southern Louisiana and occupy the lowlands adjacent to the streams. The Recent deposits are especially abundant in the broad valley of the Mississippi and its principal tributaries. The largest plants in Louisiana for the production of clay products are in the areas of the Pleistocene and Recent deposits, and for that reason a large number of samples was collected from these deposits. Samples 2, 7, 10, 11, 12, 14, 15, and 26 are from Recent deposits, and samples 1, 8, 9, 13, 16, 17, 18, 19, 24, and 25 from Pleistocene deposits. The principal localities where Pleistocene samples were collected are Baton Rouge, Lafayette, Lafayette Parish; Slidell, St. Tammany Parish; Opelousas, St. Landry Parish; and Lake Charles, Calcasieu Parish. The samples from the Recent deposits were collected from terraces in the river valleys at Alexandria, Shreveport, and Delhi. The samples from Baton Rouge and Delhi represent clays that may be vitrified below 1,230° C., and the sample from Lafayette was one of the best clays collected in the State. The samples from Slidell and Baton Rouge were tested with particular care, because it was thought that if the clays were found to be suitable for the manufacture of fireproofing and similar materials they might be utilized in the manufacture of these materials for the New Orleans market. A number of samples were taken from the Salmen Brick & Lumber Co.'s pits at Slidell, representing beds of different character, and it was found that although some of them were too sandy for the manufacture of hollow blocks and tile, others would be suitable for those purposes. In order to utilize the better grade materials it would be necessary to separate the sandy materials from the more plastic clays. The samples from Baton Rouge were not suitable for the manufacture of fireproofing materials, but if the surface material represented by sample 7 were mixed with the more plastic clays represented by the other samples in proper proportions the mixture could be used for such products.

CLAY LOCALITIES.

Lafayette.—The sample obtained at Lafayette (No. 1) was from the basal clay bed of the accompanying section, which differs from the upper bed in being slightly lighter colored and containing dark-colored granules.

Section at the pit of the Roy Brick Co., Lafayette.

	Feet.
Dark silt loam	2- 3
Yellow clay	8-10
Yellow "buckshot" clay	10+

Lake Charles.—The sample collected at the Delatte & LaGrange brickyard, Lake Charles (No. 16), is a composite of all the clay beds in the pit.

Section at the brickyard of Delatte & LaGrange, Lake Charles.

	Feet.
Dark sandy loam	1-2
Light-gray silty clay containing small nodules of iron oxide	5
Dark-red clay with thin layers and lenses of sand and locally some shells	6
"Quicksand"	3

Another brickyard at the south edge of Lake Charles afforded an opportunity to examine a somewhat better section of materials. Thin laminae of sand occur in the clay at this pit.

Section of the clay pit at the south edge of Lake Charles.

	Feet.
Dark sandy loam	1-2
Dark-gray clay containing small nodules of limonite	3
Dark-gray clay, mottled yellow, containing shells at some localities	8

Slidell.—The sections at Slidell differ so much that no satisfactory description can be given. The samples were all collected in a long pit belonging to the Salmen Brick & Lumber Co. The thickness of the clay exposed in this pit ranges from 6 to 8 feet and the samples were taken at intervals along the east wall of the pit beginning at the north end.

Sample 18 was obtained from a dark clay bed 3 feet thick; sample 17 from a bed of mottled blue clay 3 feet thick; sample 25 from a bed of blue clay, mottled gray, 5 feet thick; sample 24 from a clay similar to that of sample 25 but slightly more sandy; sample 8 from a massive gray clay about 6 feet thick; sample 9 from a bed of blue clay, mottled buff, 6 feet thick; sample 5 from blue clay dredged from a canal at a depth of 7 feet. Sample 9 is one of the two samples obtained in Louisiana that burn buff instead of red. This clay pit contains a very large variety of materials which can probably be utilized in many different ways by arranging suitable mixtures of materials from different beds.

Delhi.—The sample obtained at Delhi (No. 14) was a composite of the two beds shown in the section.

Section of alluvium at Delhi.

	Feet.
Red clay	2
Gray clay	5

Baton Rouge.—Several samples were obtained in the Connell brickyard, Baton Rouge, as indicated in the subjoined section.

Section at the W. P. Connell brickyard, Baton Rouge.

	Feet.
Fine sandy silt	⅓–½
Chocolate-colored clay	4
Fine silty sand	1–1½
Chocolate-colored clay	6
Sample 7 included the materials to this depth, with the exception of the fine sandy silt at the surface.	
Buff clay	4½–5
This bed was represented by sample 10.	
Buff clay containing concretions of calcium carbonate	1½–2
Sample 11 was obtained from this bed.	
Blue clay mottled yellow	45
Fine brown silty sand	1
Blue clay	15
Sample 12 included all the beds of clay below sample 11.	
Fine yellow sand	2+

Monroe.—The sample obtained near Monroe (No. 15) was a composite of the clay beds below the sandy loam.

Section in the clay pit of the Monroe Brick Co., 1 mile east of Monroe.

	Feet.
Yellow sandy loam	3–4
Light-brown clay	8
Dark-blue clay with some shells	4

Shreveport.—The clay at Shreveport contains fragments of partly decayed wood and leaves. The sample (No. 2) was typical of the deposit below the sandy loam. A similar clay was collected near Alexandria, but there was so much water in the pit that the materials could not be examined.

Section in the clay pit near Red River, Shreveport.

	Feet.
Red sandy loam	1½
Massive red clay, with a few thin partings of fine sand	15

TESTING OF THE CLAY SAMPLES.

The clay samples were tested in the laboratory of the Bureau of Standards at Pittsburgh, and the accompanying table, together with the following description of the methods of examination, show the character and results of the tests.

PREPARATION OF THE CLAY.

Each sample of clay was ground dry in a 5-foot Stevenson pan. If the clay contained hard lumps or pebbles that were not reduced by grinding, it was screened dry through an 8-mesh sieve. After the clay was ground to the desired fineness water was added and the sample tempered in the pan until a consistency suitable for manufacture by the stiff clay process was obtained.

The plastic clay was passed through a small Mueller auger machine, having a circular die 2¾ inches in diameter. By means of a miter box 30 disks 1 inch in thickness were cut from the column of clay molded by the circular die. The samples of clay received were numbered from 1 to 26 consecutively. Five of the wet disks were weighed, carefully dried, and again weighed, and the percentage of water required for tempering the clay was determined from the average losses in weight of the five test pieces.

The volumes of three cylindrical pieces of each clay were measured in a voluminometer, the pieces were dried, and the volumes were again determined. The average volume shrinkage in terms of the dry volume was determined from the decrease in volume due to drying as measured.

DRYING TREATMENT.

The test pieces of each clay were first dried in air at room temperature and then in a gas drier at 80° C. before placing in the test kiln. Clays whose machine-made test pieces cracked during the drying treatment were remolded. The clay was reground and tempered with water, and briquets were prepared by pressing it by hand into a brass mold 4 inches in length, 2 inches in width, and 1 inch in depth. The hand-made test pieces were dried in the same manner as the pieces molded on the auger machine.

BURNING.

The burning was done in a down-draft test kiln, fired with natural gas. A number of the test pieces of each clay were placed in the kiln in such a manner that two trials of each clay could be drawn at different temperatures. The first trial pieces were drawn at 950° C., and other pieces at 20° intervals until the clay reached its maturing point or temperature.

The temperatures in the kilns were measured by platinum-rhodium thermocouples, the kiln temperature being increased at the rate of 40° C. an hour after 950° C. was reached. As the hot trial pieces were drawn from the kiln they were placed in an auxiliary furnace, heated to redness for the purpose, and the whole allowed to cool down slowly.

POROSITY OF THE BURNED TEST PIECES.

The porosities of the burned test pieces were determined in the usual manner by substituting in the formula $\frac{W-D}{W-S}\times 100$ = per cent of porosity, in which D=dry weight of the test pieces, W=wet weight of the test piece (absorption in vacuo), S=suspended weight of the saturated piece.

By plotting a porosity temperature curve, a very clear idea of the vitri behavior of the clay may be gained, and also an indication as to the class that may be manufactured from the clay.

Information as to the color, hardness, tendency to effloresce, etc., was g from the burned test pieces drawn from the kiln.

SUMMARY OF RESULTS.

Perhaps the two greatest difficulties encountered in the working of the cla the lack of plasticity and bonding power of some of the clays and the excessi ticity and tendency to crack in drying of others.

All of the samples except Nos. 17 and 20 developed a red color in the burning. clays, samples 3, 4, 6, 9, 17, 18, 19, 24, and 25 preserved an open structure wit decrease in porosity when fired to temperatures as high as 1,250° C. These clay sandy, some being very low in plasticity and others developing good workin ticity. It is not commercially practicable to manufacture vitrified ware from of this type, owing to the high temperatures which they require.

Samples 7, 13, and 14 are sandy in character, yet may be vitrified at temper below 1,230° C., differing in this respect from the remainder of the sandy clays.

Samples 1 and 21 show perhaps the best working, drying, and burning beha all the clays tested.

The buff-burning clays, Nos. 17 and 20, have good working and drying qu but maintain an open structure at relatively high temperatures.

Samples 2, 15, and 16 are of inferior quality. In addition to their excessive ticity and tendency to crack during drying, these clays are easily overburned.

None of the clays are suitable for the manufacture of vitrified clay products, as paving brick and sewer pipe. Those showing excessive plasticity require the tion of sand to make them workable. On the other hand the excessively sandy rials must be mixed with plastic clay to render them fit for manufacturing pur By thus improving the working qualities, when necessary, these clays can be suitable for common bricks, drain tile, hollow bricks, and the simpler shapes of proofing.

SECTIONS OF THE CLAY-BEARING FORMATIONS LOUISIANA.

The accompanying diagrams (figs. 14, 15) show the general ch acter of the principal clay-bearing formations of Louisiana, altho these formations vary in character from place to place and the sa of one part of a section may be replaced by clays at another locali or vice versa. However, at any locality a considerable portion of formations will be clay.

Figure 14, A, shows the general character of the Pleistocene deposits, the Citronelle formation, and the Pascagoula clay in Louisiana east of Mississippi River.

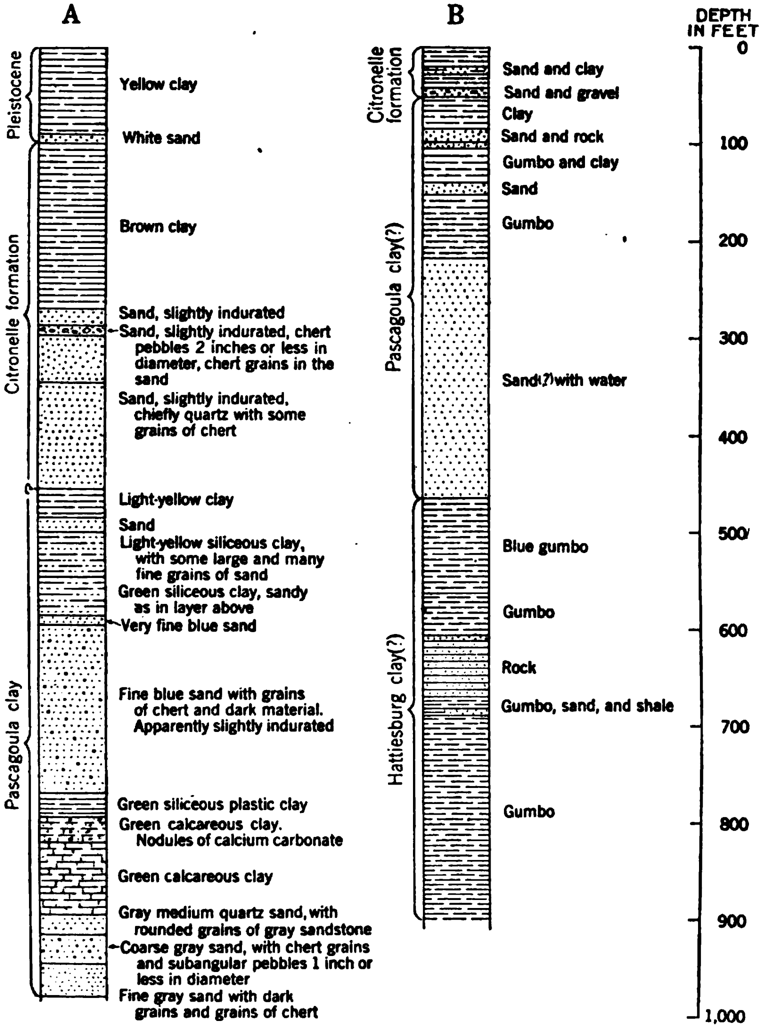
A
Pleistocene
Yellow clay
White sand
Citronelle formation
Brown clay
Sand, slightly indurated
Sand, slightly indurated, chert pebbles 2 inches or less in diameter, chert grains in the sand
Sand, slightly indurated, chiefly quartz with some grains of chert
?
Pascagoula clay
Light-yellow clay
Sand
Light-yellow siliceous clay, with some large and many fine grains of sand
Green siliceous clay, sandy as in layer above
Very fine blue sand
Fine blue sand with grains of chert and dark material. Apparently slightly indurated
Green siliceous plastic clay
Green calcareous clay. Nodules of calcium carbonate
Green calcareous clay
Gray medium quartz sand, with rounded grains of gray sandstone
Coarse gray sand, with chert grains and subangular pebbles 1 inch or less in diameter
Fine gray sand with dark grains and grains of chert
B
Citronelle formation
Sand and clay
Sand and gravel
Clay
Sand and rock
Gumbo and clay
Sand
Gumbo
Pascagoula clay(?)
Sand(?) with water
Hattiesburg clay(?)
Blue gumbo
Gumbo
Rock
Gumbo, sand, and shale
Gumbo
DEPTH IN FEET
0
100
200
300
400
500
600
700
800
900
1,000

FIGURE 14.—Diagrams of wells showing the general character of clay-bearing formations of Louisiana. A, Well of B. A. Bass, East Baton Rouge Parish; B, Well of Gulf Land & Lumber Co., Fullerton, Vernon Parish.

Figure 14, B, shows the general character of the Citronelle formation, the Pascagoula clay, and the Hattiesburg clay in western Louisiana.

Figure 15 shows the general character of the Hattiesburg clay and the Catahoula and Fayette sandstones. The descriptions of materials shown in this diagram are generalized. Many of the sandstones contain clay beds thick enough for the manufacture of clay products, and most of the clay beds contain some lenses and layers of sand, though not enough to interfere with the exploitation of the clays.

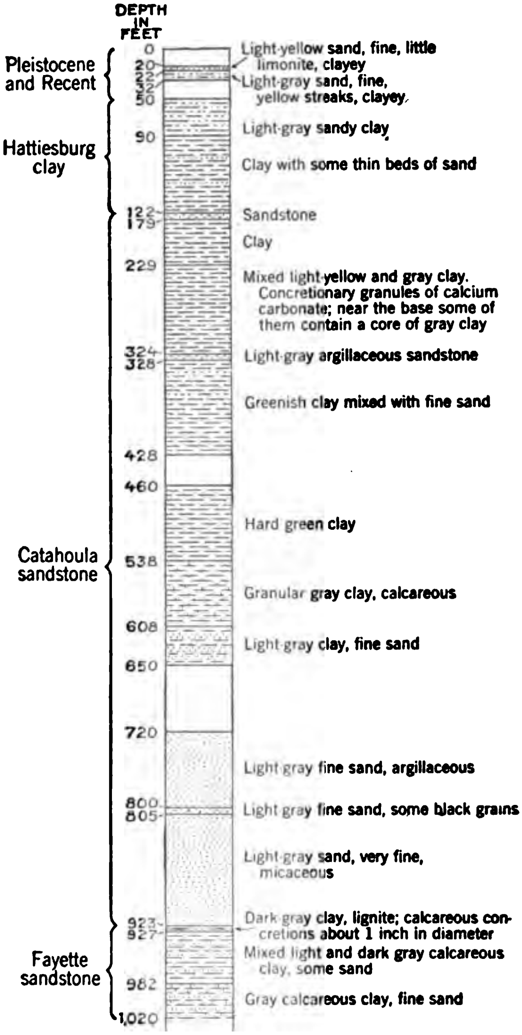
DEPTH IN FEET
Pleistocene and Recent
Hattiesburg clay
Catahoula sandstone
Fayette sandstone
0
20
22
32
50
90
122
179
229
324
328
428
460
538
608
650
720
800
805
923
927
962
1,020
Light-yellow sand, fine, little limonite, clayey
Light-gray sand, fine, yellow streaks, clayey
Light-gray sandy clay
Clay with some thin beds of sand
Sandstone
Clay
Mixed light-yellow and gray clay. Concretionary granules of calcium carbonate; near the base some of them contain a core of gray clay
Light-gray argillaceous sandstone
Greenish clay mixed with fine sand
Hard green clay
Granular gray clay, calcareous
Light-gray clay, fine sand
Light-gray fine sand, argillaceous
Light-gray fine sand, some black grains
Light-gray sand, very fine, micaceous
Dark-gray clay, lignite; calcareous concretions about 1 inch in diameter
Mixed light and dark gray calcareous clay, some sand
Gray calcareous clay, fine sand

FIGURE 15.—Diagram of well at Pineville, Rapides Parish, La.

ORE DEPOSITS OF THE NORTHWESTERN PART OF THE GARNET RANGE, MONTANA.

By J. T. Pardee.

LOCATION AND ROUTES OF ACCESS.

The area described in this report is in Missoula, Granite, and Powell counties, Mont., about 30 miles southeast of Missoula. It extends from Clinton eastward beyond Bearmouth and from Clark Fork northward into the drainage basin of Blackfoot River, covering in all about 400 square miles. Its southern part is traversed by the Northern Pacific and the Chicago, Milwaukee & St. Paul railways, from which the different mining camps are reached by wagon roads from 3 to 10 miles in length. The most convenient points of departure from the railways are Bearmouth for Garnet, Coloma, and Top o' Deep; Bonita for Copper Cliff; and Clinton for the mines of the Clinton district. Many of the mining camps may be reached also from Potomac, a farming and logging town on the road from Missoula to Ovando. As a whole, the area is but sparsely inhabited, and its chief industries in addition to mining are agriculture and lumbering. (See fig. 16.)

FIELD WORK AND ACKNOWLEDGMENTS.

Felan and Tenmile creeks, a part of the Clinton district, and a few tracts elsewhere were examined by E. L. Jones, jr., in 1911, and some geologic mapping northwest of Bearmouth was done by T. H. Rosenkranz in 1913. A reconnaissance of the remainder of the field, chiefly in August and September, 1916, was made by the writer, who received from the mining men cheerful and unstinted responses to practically all requests for information. Among those to whom special acknowledgment is due are Messrs. J. L. Templeman and H. G. Klenze, of Butte, and F. A. Davey and Ludwig Mussigbrod, of Garnet. The writer is also indebted to W. T. Schaller, of the Geological Survey, for the determination of several minerals, and to

F. C. Calkins, also of the Survey, for the microscopic examination of some of the rocks.

Although brief descriptions of some of the mines have appeared from time to time in the mining journals, no reports covering all of the area here described have hitherto been published.

SUMMARY.

Bear Creek, an affluent of Clark Fork east of Missoula, was a large and early contributor to the placer production of Montana. The character of the deposits was discovered in 1865, and gold to the value of $5,000,000 or more was washed out within a few years. Elk Creek also yielded abundantly, and the total placer production of the area is estimated to be between $6,000,000 and $10,000,000. Quartz lodes around Garnet worked at different times, chiefly since 1896, have yielded $1,500,000 in gold and considerable copper and silver. In addition, moderate amounts of copper, lead, and silver have been produced by lodes in neighboring areas, mainly in the Clinton district.

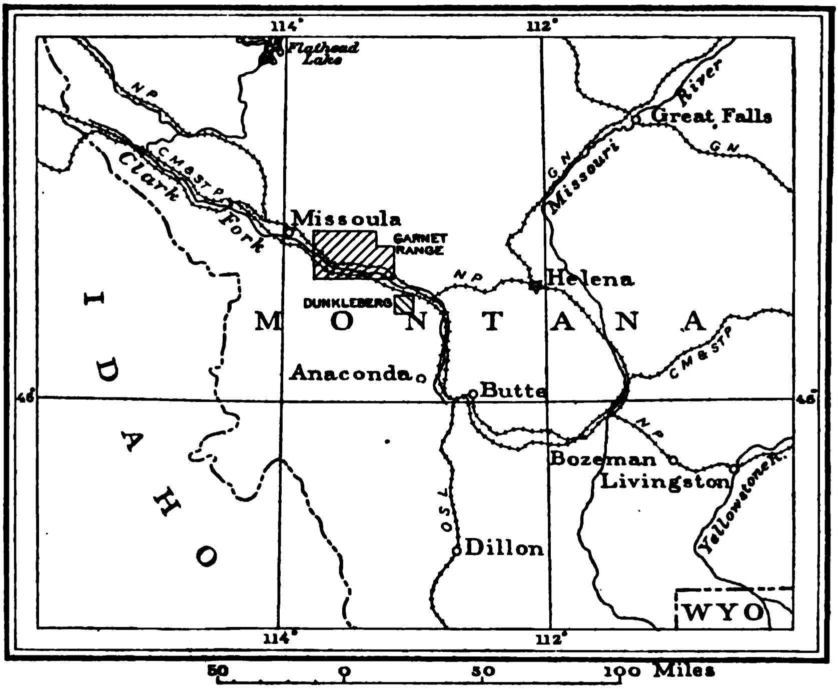

FIGURE 16.—Index map showing location of northwestern part of Garnet Range and Dunkleberg mining district, Mont.

The gold-bearing veins at Garnet and vicinity occur in granodiorite and in the adjoining quartzite and schist. Generally the veins are narrow and rich, containing auriferous pyrite and chalcopyrite, with some tetrahedrite and galena that were introduced later. At Copper Cliff enargite and abundant silica were introduced to form the cement in a quartzite breccia. In the Clinton district chalcopyrite is the primary ore mineral in lodes formed in granodiorite, and here and there in the general region bodies of silver-bearing galena occur in limestone.

The ores were deposited by solutions believed to have been given off by granodiorite bodies which came to place in late Cretaceous or early Tertiary time. Most of the mines show no evidence of being exhausted, and new discoveries and increased mining activity are looked for throughout the region.

GEOGRAPHY.

The area described herein is in the drainage basin of Clark Fork about 50 miles west of the Continental Divide. It includes the northwestern part of the Garnet Range, Camas Prairie, and part of Hellgate Canyon, as the gorge of Clark Fork between Missoula and Drummond is locally called. Clark Fork crosses the southern part of the area, following a nearly westward course to its junction with Rock Creek, where it turns sharply northward. Blackfoot River, for the most part north of the area, touches its northwest corner and joins Clark Fork at Bonner, 10 miles farther west.

A somewhat irregular watershed that has a general easterly direction and forms the main summit of the Garnet Range divides the area into two nearly equal parts. The drainage of the northern part is mostly collected by Elk and Union creeks, affluents of Blackfoot River, and that of the southern part flows directly into Clark Fork. Because of irregularities in many of the numerous small streams the drainage plan appears complex in detail. Most of the streams are perennial, and Clark Fork and Blackfoot River are fairly large and swift, their combined flow being used at Bonner to generate considerable power. Both rivers are subject to heavy annual freshets, and during an unusual flood in 1908 Clark Fork ruined many farms and destroyed practically all the railroads in Hellgate Canyon.

Timber is generally abundant, the highlands being thickly covered with the smaller conifers and the lower slopes containing groves of yellow pine. Lumbering, which has been carried on extensively during the last 30 years, has stripped the timber from most of the Clark Fork valley and the slopes about Camas Prairie.

The bottom lands in Hellgate Canyon and Camas Prairie and the adjoining bench lands are fertile and are cultivated chiefly for hay and grain. Apples, cherries, and other equally hardy fruits grow also, and the more gradual slopes afford pasture for considerable stock. In the higher areas the winters are rather long, there is considerable snow, and frost is likely to occur any summer night.

PHYSIOGRAPHY.

The most obvious characteristic of the area described as viewed from the main traveled route along Clark Fork is its roughness. No smooth or level ground except a narrow flood plain can be seen. The valley sides rise abruptly to imposing heights, the slopes commonly showing cliffs and crags and generally being as steep as soil or loose rock can lie. As far as the view extends up the V-shaped side valleys that branch out right and left at short intervals a similar ruggedness prevails.

In a general view, however, such as that from an elevated point like Baldy Mountain, the region appears very different. The valleys that roughen it so extensively can not be seen, except those near at hand, and what appears to be a smoothly undulating or slightly hilly plain, above which isolated mountains or groups of mountains rise here and there, stretches away on all sides. Evidently the area as a whole is a rather flat but extensively dissected upland.

The origin of this upland and the valleys that almost destroy it is an interesting subject, not only from the viewpoint of the geologist but for the bearing it has upon the mineral deposits, particularly the distribution of the placer gravel.

The highest point in the area is a peak 7,093 feet above the sea, 4 miles northeast of Garnet, and the lowest is the town of Clinton, whose altitude is 2,467 feet. The main valleys, however, are about 2,000 feet deep, and the relief generally does not exceed 2,500 feet.

The steep slopes occupy about three-fourths of the area, the remainder being in part flat lowlands along the streams and in part flat or undulating surfaces on the divides. Practically all the lowland flats are confined to the Clark Fork valley and Camas Prairie. The former contains a flood plain from a quarter of a mile to a mile in width, and Camas Prairie is a somewhat larger flat composed of the flood plains of Union Creek and several tributary streams.

Camas Prairie and the slopes that adjoin it form a large flaring basin that, except for a narrow drainage outlet at the west, is completely inclosed. Camas Basin, as this feature may be called, is about 2,000 feet deep, 6 miles wide, and 10 miles long, and its major axis trends northwest. In strong contrast to the other valleys the sides of Camas Basin, viewed without regard to the gulches and ravines that channel them, slope gradually and curve smoothly into the central lowland.

The flats or undulating surfaces on the divides are worthy of more than passing notice. Most of them lie between elevations of 6,000 and 6,500 feet, and they surmount practically every divide that reaches those heights. Although perhaps more extensive and continuous along the main watershed, they are common on the lateral spurs out to points that look down on Clark Fork or the other principal streams. As already mentioned, a general view shows that the summit flats fall in place like the surface of an undulating plain, and in fact the flats are remnants of a formerly unbroken surface that was nearly a plain—in other words, a peneplain. The general relief of the peneplain is not more than a few hundred feet, but here and there is a higher isolated summit like Baldy Mountain or Anderson Hill. Some of these summits, as for example a high point east of the head of Deep Creek, are remnants of lava flows poured out on the peneplain; others, like Anderson Hill, are the parts of some older upland not completely reduced when the peneplain was formed.

Less noticeable but equally significant physiographic features are some broad passes in the main divides and flat shoulders or benches on the sides of the valleys. Viewed together, these are remnants of surfaces parallel to the peneplain and slightly below it, or, in other words, remnants of broad valleys in the peneplain. The pass at the head of Elk Creek, at an elevation of 5,840 feet, and the basin drained by Gambler Creek are the remnants of one shallow valley nearly a mile wide, which had a northwest course, and whose stream probably flowed in the same direction and was the ancestor of Elk Creek. A similar valley crossed the main divide a little west of Coloma, and another crossed from the head of Tenmile Creek to the basin of Union Creek, passing a mile west of Copper Cliff. Stones Flat, on the main divide, at an altitude of about 6,200 feet, is a remnant of another ancient valley and is especially interesting because it contains a deposit of gold-bearing stream gravel. The course of this valley is about north, but the stream that deposited the gravel has been diverted and its identity lost.

That the peneplain and its valleys were formed by erosion is plainly shown by the occurrence of their remnants on different kinds of rocks and without regard to the structure. In one locality they occur on granodiorite, in another on quartzite or limestone, and whether the rocks are tilted or not makes no difference. East of the area described the peneplain was developed throughout the Garnet Range, and its remnants are very abundant also in the Sapphire Mountains, which occupy the region between Clark Fork and Bitterroot River. Across the Bitterroot and Missoula valleys it is found extending over a large part of central and northern Idaho.[1]

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[1] Lindgren, Waldemar, A geological reconnaissance * * * in Montana and Idaho: U. S. Geol. Survey Prof. Paper 27, p. 14, 1904. Ransome, F. L., and Calkins, F. C., The geology and ore deposits of the Coeur d'Alene district, Idaho: U. S. Geol. Survey Prof. Paper 62, p. 21, 1908. Umpleby, J. B., Geology and ore deposits of Lemhi County, Idaho: U. S. Geol. Survey Bull. 528, pp. 23–30, 1913.

Most observers consider the peneplain to have been formed in early Tertiary time. In the Garnet Range no facts are known that determine its age within narrow limits. Lava beds that lie upon it in the eastern part of the area described are in turn overlain by Oligocene sediments farther east, and in the eastern part of the Garnet Range the peneplain cuts across tilted rocks of Cretaceous (Colorado) age. Therefore it was formed after late Cretaceous rocks had been folded and before Oligocene beds were laid down.

Except for differences in magnitude the other surface features of the wide region mentioned in the foregoing paragraph are generally similar to those of the area particularly considered in this report. Narrow steep-sided valleys occur without number, the general monotony being relieved in places by wide, smooth depressions similar to Camas Basin, or by isolated peaks and ranges that rise above the general summit level. All parts of the region have apparently had the same general history, the main events in which are as follows: In early Tertiary time, during a period in which this part of the earth's crust was free of mountain-building or other movements—in other words, during a period of crustal stability—the area generally was reduced to a low elevation, the surface approaching a plain, or at least being without strong relief. Afterward a general uplift of several thousand feet occurred, as a result of which the streams cut deeply into the uplifted region, producing its present ruggedness.

The details of this uplift and erosion, however, were by no means as simple as the foregoing brief statement might imply. The upward movement was neither continuous nor everywhere the same, the result being a more or less widespread and extensive warping, by which features like Camas Basin were formed. In addition to warping, lavas were extruded here and there both before and during the dissection of the peneplain, all of which caused many changes in the drainage plan. For example, at an early date Clark Fork, or rather a stream occupying the present latitude of that river, probably flowed east from a point near Nimrod, a conclusion suggested by the fact that some tributaries, Harvey Creek and Bear Creek among them, incline to the east or opposite to the present course of the main stream. From Nimrod westward, however, there is no evidence of a reversal, and the stream gathered between that point and Rock Creek was merely a small tributary of Rock Creek, a conclusion supported by the fact that Clark Fork now turns sharply north at the junction, abandoning its own general direction for that of its present tributary. Doubtless the warping early caused the waters east of Nimrod to turn to their present direction, but Rock Creek, having become intrenched, has preserved the evidence of its former dominating rank. Significant features in the valleys of the main streams are numerous bends and, along the Clark Fork valley in particular, low terraces or benches and small transverse spurs, of which Beaver Tail Hill and Medicine Tree Hill are examples. In places the bends give the valleys rather serpentine courses, and for the most part they are thought to be inherited from meanders followed by the streams when they flowed near the surface of the peneplain. The benches and flat spurs are of more recent origin. Apparently, when within 200 feet of its present level, Clark Fork ceased down cutting, probably because of a temporary dam farther down, as suggested in the next paragraph, long enough to widen its valley somewhat and floor it with gravel. When the stream was rejuvenated, probably through destruction of the dam, down cutting was resumed, and parts of the graveled floor were left high and dry as benches and flat spurs, the spurs being formed between meanders through which the stream had traveled from side to side within the limits of its valley.

Clark Fork is now again widening its valley and covering it with gravel, because of a dam of late glacial outwash thrown across it by Blackfoot River at Bonner. Whether the former widening and gravel deposit were due to a similar cause is not known, but it is thought probable that they were, in view of the well-known fact that an earlier Pleistocene glaciation occurred in this general region.

GEOLOGY.

STRATIGRAPHY.

GENERAL FEATURES.

The area described herein is part of the borderland between the great pre-Cambrian shale and quartzite area of northwestern Montana and a province of Paleozoic and later sediments deposited along the main axis of the Rocky Mountains. In its southeast corner Cretaceous shale and sandstone are exposed. Toward the northwest older beds, including at least 4,000 feet of Paleozoic limestones, succeed one another in descending order before the Algonkian shales and quartzites are reached. The latter occupy at least two-thirds of the area described, are 5,000 feet or more in thickness, and belong to the upper part of the Belt series. In common with many other parts of the general region this area does not show angular discordances between any of the rocks mentioned, all the beds having apparently remained undisturbed until the last was laid down. Therefore breaks in the sedimentation are not readily detected, and a great gap between the Cambrian and Belt rocks would hardly be suspected in a casual examination. So far as the observations go, however, the Flathead quartzite, the oldest Cambrian formation known in the general region, is not present everywhere in the area described.

In several localities intrusive igneous rocks, chiefly granodiorite, have broken through the sedimentary beds mentioned, some of the bodies at least not having come to place until after sediments of Colorado age had been folded. The areal outlines of the granodiorite commonly advance up the gulches and retreat around the intervening spurs, showing that the intrusive bodies are only partly uncovered, and the exposures are so much alike that it seems not unreasonable to regard them all as parts of a single huge deeply buried mass. It does not follow, however, that all the offshoots of this mass arose at the same time. In fact, the body along Clark Fork near Willis, which occupies a lower position than the others, is so much finer grained that it probably crystallized under a very thin cover, a condition that could have been brought about only by considerable erosion after the earlier eruptions. No metalliferous lodes or strongly metamorphosed rocks are known about the granodiorite at Willis, a possible explanation being that rapid solidification of the intrusive body did not give time for mineralizing solutions to collect or escape.

Small dikes of a light-gray granodiorite porphyry are moderately abundant in the metamorphic sediments and in the granodiorite of the Garnet and Clinton mining districts. Pegmatite and aplite are uncommon. Lavas extruded upon eroded surfaces of granodiorite and the Cretaceous and older sediments occupy large areas east of Top o' Deep, in and near Bearmouth, and form small patches elsewhere. Most of these lavas are andesite or related rocks. Rhyolite is fairly abundant and basalt uncommon. Beginning with the oldest, their general order of extrusion seems to be rhyolite, andesite, and basalt. The main bodies of andesite and rhyolite are continuous with masses farther east that underlie sediments of Oligocene age. Surficial deposits consisting of Tertiary light-colored silts containing volcanic ash and gravels of later age are not areally important except in Camas Prairie and the Clark Fork valley.

LITHOLOGY.

Notes on the lithology are given in condensed form in the following table, in which the subdivisions indicate probable correlations with the rocks of the Philipsburg quadrangle:[1]

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[1] Calkins, F. C., and Emmons, W. H., U. S. Geol. Survey Geol. Atlas, Philipsburg folio (No. 196), 1915.

Partial sections of rocks in the northwestern part of the Garnet Range, Mont.

Sedimentary rocks.

System.	Series.	Formation.	Character.
Quaternary.	Recent.	Alluvium.	Silt, sand, and gravel that form flats along the streams and are locally gold bearing.
	Pleistocene.	Terrace gravels.	Moderately thick deposits of subangular to smoothly washed gravel that covers the terraces or bench lands around Camas Prairie and Sunset Valley. Small patches of river gravel on terraces or bars along Clark Fork about 100 feet above the stream. Locally gold bearing.
Tertiary.	Oligocene or Miocene.	Lake beds.	Fine light-colored massive silts underlying the bench lands in Camas Prairie, Sunset Valley, and small tracts in the extreme southeastern part of the mapped area. Generally concealed by superficial material and to be seen only in road cuts or other artificial exposures. As a rule the material is sharp and gritty, owing to particles of volcanic glass that glint when specimens are turned in the sunlight. At the southeast corner of the mapped area the lake beds contain a 5-foot bed of subbituminous coal.[a]
Cretaceous.	Upper Cretaceous.	Colorado formation.	Fissile black shale, poorly exposed at the southeast corner of the mapped area.
	Lower Cretaceous.	Kootenai formation.	1,000 feet or more of variegated shales, chiefly purple and maroon, together with some thin beds of limestone. Subdued exposures along Clark Fork in the vicinity of Hellgate and eastward. In the railroad cut at Hellgate the maroon shale shows concretionary forms as large as a cart wheel.
Jurassic.	Upper Jurassic.	Ellis formation.	100 feet or more of flaggy cross-bedded gray sandstone and some buff-weathering shale and limestone, rather poorly exposed along Clark Fork above and below Hellgate.
Carboniferous.	Pennsylvanian.	Quadrant formation.	300 feet or more of grayish-brown and yellow quartzite and red shale overlies the Madison limestone in a narrow area extending from Tenmile Creek southeastward, also west of Little Bear Creek. Outcrops of the quartzite are bold; in places the rock looks like flint and commonly is crushed to a breccia superficially stained red or brown. The red shale is poorly exposed. A little phosphatic sandstone overlies the quartzite in the extreme southeastern part of the area surveyed, but it dies out to the northwest. This phosphatic sandstone probably represents the Phosphoria formation.
	Mississippian.	Madison limestone.	1,000 feet or more of light-gray and blue limestone, fossiliferous, cherty, and otherwise similar to the Madison of the general region. Forms picturesque cliffs and crags along Clark Fork east of Bearmouth and along Bear Creek generally from Tenmile Creek down. Also extensively exposed along the East Fork of Cramer Creek and the upper courses of streams that enter Clark Fork from the north between Nimrod and Willis. Some of the outcrops east of Bearmouth are superficially stained pink with ocher from the red shale member of the overlying Quadrant.
Devonian.	Middle Devonian.	Jefferson limestone.	Crags of gray and brown limestone along Bear Creek near Packer Gulch. Several hundred feet of gray to black limestone along North Fork of Cramer Creek near the Chloride mine.
Silurian (?).		Maywood formation.	A bed of calcareous quartzite about 100 feet thick.

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[a] Pardee, J. T., Coal in the Tertiary lake beds of southwestern Montana: U. S. Geol. Survey Bull. 531, pp. 242-243, pl. 14, 1913.

Partial sections of rocks in the northwestern part of the Garnet Range, Mont.—Continued.

Sedimentary rocks—Continued.

System.	Series.	Formation.	Character.
Cambrian.	Middle and Upper Cambrian.	Red Lion formation.	About 300 feet of siliceous limestone measured above the Hasmark at the Cramer Creek section. Composed of thin layers of buff to pink shale and chert alternating with dove-gray limestone. Similar beds are exposed also at a point about two-thirds of the way to the Chloride mine along the trail that follows the divide westward from Copper Cliff.
		Hasmark formation.	Fine-grained dull-blue or lead-gray limestone; weathered surface a dirty white or dove-gray. Some beds have a concretionary structure, and some that are black show light-colored irregular branching or twiglike forms. A section 570 feet thick measured along Cramer Creek at Parent's ranch is made up of dove-gray limestone beds with a few thin, yellow and pink siliceous laminae. Some specimens of the limestone effervesce freely with cold dilute acid and others do not; weathered surfaces feel gritty. Near the granodiorite contacts at Garnet and elsewhere the Hasmark is changed to a white crystalline rock resembling coarse-grained marble that breaks down under the influence of weathering to a carbonate sand. Adjoining the contact the metamorphosed rock is commonly stained green with chlorite, and considerable portions of it are replaced by brown garnet. At moderate distances the original blue and gray colors of the limestone are not destroyed, but as a rule slender needles of white tremolite are developed.
		Silver Hill formation.	Gray and white banded calcareous shale at Garnet and along Bear Creek above First Chance Gulch. Also lead-gray shales along road above the Dandy and Haparanda mines east of Garnet and in some of the workings at the Copper Cliff mine. A section along Ryan Creek about a mile above its mouth shows about 100 feet of siliceous laminated limestone and calcareous white or pale-yellow quartzite below the Hasmark formation and above a yellowish-brown quartzite that in turn rests upon undoubted Belt beds. In the middle of the siliceous limestone is a 6-foot bed of conglomerate made up of well-rounded quartzite cobbles firmly cemented in a sandy, limy matrix. At Garnet portions of the Silver Hill formation are changed by metamorphism to a garnet-epidote hornstone.
		Flathead quartzite.	Rather pure buff to gray banded quartzite on the summit of Anderson Hill east of Garnet; reddish-brown brecciated quartzite along Ryan and Marcella creeks north of Willis. Evidently not very thick, and apparently not developed over the whole region.
Algonkian.	Belt.		Deep-red to grayish-green indurated shales and interbedded quartzitic sandstones that generally show small flakes of mica and form bold exposures along both sides of the Clark Fork valley below Bearmouth and in the canyons of tributary streams. A typical section, 4,000 feet thick, measured along Cramer Creek below the mouth of its west fork, shows chiefly deep-red shale below and red or purple shale interleaved with pale-yellow or gray sandstone above. Many of the upper purple beds show light-colored spots and streaks. Near the large intrusive bodies contact metamorphism has altered the more sandy layers to mica schists, and others to argillite or hornstone. Specimens from the upper beds, which crop out in the vicinity of Garnet, commonly show abundant dark-gray spots or knots that under the microscope prove to be either aggregates of fine biotite or crystals of cordierite. Generally the cordierite crystals show the outlines of short thick prisms a quarter of an inch in diameter and inclose a multitude of fine mica flakes and quartz grains. In addition some of the rock specimens contain a little secondary zoisite and feldspar. Shaly beds in contact with the granodiorite near Clinton are changed to dense purple and green hornstone.

Partial sections of rocks in the northwestern part of the Garnet Range, Mont.—Continued.

Igneous rocks.

Geologic age.	Formation.	Character.
Middle Tertiary.	Basalt.	Small patches of dense fine-grained black lava near Bearmouth. Under the microscope a specimen from an outcrop 2 miles up Lannen Creek is a typical olivine basalt showing plagioclase laths in a cryptocrystalline groundmass. It appears to be later than the hypersthene andesite.
	Dacite.	A medium-grained gray porphyritic lava that looks not unlike granodiorite from a distance occurs along Clark Fork between Willis and Nimrod. The phenocrysts are plagioclase, and in addition there are flakes of biotite and grains of quartz in a fine-grained vitreous groundmass. This lava lies on a surface eroded almost as deeply in the Belt shale as the bed of Clark Fork and it is therefore thought to be comparatively recent.
	Hornblende and augite andesite.	Prominent outcrops along Union Creek above Camas Prairie and a few localities near by of medium-gray, strikingly porphyritic lava. An exposure halfway along the road from Union Creek to Coloma is crowded with distinctly zoned plagioclase feldspars, some of them as large as an inch in diameter. Under the microscope the fine-grained groundmass is seen to be composed of plagioclase biotite and augite, and the zones in the phenocrysts to be made up of biotite flakes. A specimen from a small mass near Shipler's cabin at Copper Cliff is less strongly porphyritic and contains hornblende and augite in about equal amounts. These rocks lie upon an eroded surface of Paleozoic and older rocks and are covered by Tertiary lake beds but were not observed in contact with the other lavas.
	Hypersthene andesite (?).	Large areas of grayish or purplish-brown fine-textured lavas exposed east of Top o' Deep and southeast of Bearmouth. Not examined microscopically, but these bodies are similar in occurrence and practically continuous with areas of hypersthene andesite in the Garnet Range farther east.
	Rhyolite (?).	Exposures south of Felan Creek and along Wood Creek and other places south and east of Bearmouth of light-gray to pink or red fine-grained dense lavas that show small quartz phenocrysts.
Late Cretaceous or Early Tertiary.	Pegmatite and aplite dikes.	Not abundant. Small dikes in the granodiorite at Garnet consist chiefly of pale-pink feldspar and quartz in coarse graphic intergrowths. A specimen from one exposed in the Dewey mine shows both orthoclase and plagioclase, the latter almost wholly altered to sericite, chlorite, and calcite. Small aplite veins were observed in granodiorite at the Pearl mine near Top o' Deep. A dike, 14 feet wide, that cuts the gabbro sill near Tyler Creek is closely related to a quartz vein and carries a little chalcopyrite. A specimen examined under the microscope is composed of albite and quartz with accessory rutile, zircon, and apatite.
	Porphyry dikes.	Small dikes of gray and greenish-gray rock showing porphyritic feldspars and biotite in a fine-grained groundmass are fairly abundant in the Garnet and Clinton districts. In a specimen from a dike near the Red Cloud mill, at Garnet, the phenocrysts are small hypidiomorphic plagioclases and the groundmass consists of feldspars, quartz, and biotite. A dike at the head of Weasel Gulch, near Top o' Deep, shows sharply outlined phenocrysts of plagioclase and orthoclase in a similar groundmass. Both dikes contain accessory iron ore and apatite.
	Granodiorite.	Light-gray granular crystalline intrusive rock exposed extensively in the vicinity of Garnet, in the Clinton mining district, and in small areas elsewhere. Except those along Clark Fork near Willis, all the exposures are very much alike in general appearance, texture, and composition. They show prisms of black hornblende, commonly one-eighth inch or more in length, and flakes of dark mica in a granular mass of medium-textured milk-white feldspars and quartz. The exposures near Willis are very much finer grained and somewhat lighter colored. Porphyritic feldspars half an inch or less in length were observed in the Garnet and Clinton exposures, especially at Clinton, but they are not common. Marginal portions of the exposed masses are generally somewhat darker with ferromagnesian minerals than other portions. A few representative specimens from the Garnet and Clinton bodies are shown by the microscope to be composed chiefly of andesine-oligoclase, quartz, orthoclase, hornblende, and biotite, with accessory iron ore (ilmenite or magnetite) and apatite. A specimen of the fine-textured body at Willis from an exposure north of the river shows the same minerals as the other bodies, but the ferromagnesian silicates are less abundant.
Pre-Tertiary.	Gabbro.	A sill 300 feet or more thick of dense, heavy dark grayish-green crystalline rock intrusive in the Belt rock south of Clark Fork between Nimrod and Bonita. Under the microscope specimens from the locality of Tyler Creek show feldspar (sodic labradorite or albite) and augite as the chief constituents, with minor amounts of hornblende, biotite, and quartz and accessory ilmenite, titanite, and apatite. Some of the original rock minerals are altered to calcite, uralite, and chlorite.

STRUCTURE.

FOLDS.

Several large folds that involve all the sedimentary rocks older than Tertiary cross the area described from southeast to northwest. In the southeastern part, along Clark Fork, the folds are tightly compressed and commonly overturned, causing the rocks to have vertical or very steep dips. A large syncline that is followed by Clark Fork for some distance above and below Hellgate and another which appears just below Bearmouth have tightly squeezed Cretaceous and Jurassic rocks and Carboniferous (Quadrant) quartzite in their cores. Toward the northwest the troughs are more open. They also rise in this direction, so that the younger formations, in consequence of the relation of this inclination to the present erosion surface, thin out, one by one, until only Belt rocks remain. The intervening anticlines carry the Belt rocks southeastward, and most of them plunge in that direction and become very tightly compressed. The gradual opening of the folds toward the northwest marks the transition from the intense deformation of the Rocky Mountain Paleozoic province to the relatively broad and simple structure that characterizes the great pre-Cambrian area of the Northwest.

FAULTS.

One of the chief structural features of this area is a large overthrust fault on a fissure that comes to the surface along the Clark Fork valley from Bearmouth to Bonita. In this locality its general course is about N. 20° W. and its dip 20°-30° SW. West of Bonita this fissure has not been traced, and east of Bearmouth its course is concealed by superficial formations, but there is some reason to think it is continuous with that of the Philipsburg fault,[1] about 20 miles to the southeast. Each fault has carried a great mass of Belt rocks from the west over Paleozoic and younger formations, and a line joining the two falls in an area underlain by Tertiary and other superficial formations that continues to separate the Belt and Paleozoic. Along the Clark Fork valley the trace of the fault is generally accompanied by as much as 100 feet of crushed or disturbed rocks, and where it crosses some low spurs north of the river it is marked by small notches. In places movement is shown along several fractures, as if one had become clogged, causing another to form behind it, and so on. The Gipsy prospect, on the west fork of Cramer Creek, is on a parallel fault that is probably a related thrust if not a branch of the main fault.

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[1] Calkins, F. C., and Emmons, W. H., U. S. Geol. Survey Geol. Atlas, Philipsburg folio (No. 196), p. 18, 1915.

There is evidence of northeasterly faulting along steeply inclined or vertical planes in the mines at Garnet, along First Chance Gulch, and elsewhere, but the displacements on these faults are generally small. Along Cramer Creek and its north fork, especially at Copper Cliff, there has been extensive crushing along a northeast plane. In addition to the normal displacements shown at Copper Cliff, the large block on the southwest side of the plane appears to have been shoved forward, or to the northeast, relative to the other block.

ORE DEPOSITS.

CLASSIFICATION.

The ore deposits of the area comprise lodes that are valuable for gold, copper, silver, and lead, and gold placers. The lodes include contact-metamorphic deposits in limestone, simple and multiple quartz veins, filled fissures, replacement veins in granodiorite and schist, and replacement deposits in limestone not directly related to igneous contacts. The lodes are most conveniently described as natural groups about certain localities, and the terms Garnet district, Coloma district, etc., as used in this report include only the mines near those places.

LODES.

GARNET DISTRICT.

HISTORY AND PRODUCTION.

The bulk of the mineral wealth, except placer gold, produced by the region considered in this report has been taken from a small area surrounding the town of Garnet. In 1867, while placer mining was at its height, the Lead King, Grant & Hartford, and Shamrock veins were discovered, and about 1873 S. I. Ritchey located the Nancy Hanks. Except that small lots of ore were worked from time to time in an arrastre down Bear Creek, the productive period of the camp did not begin until 1896. In that year the rich "red-ore" body of the Nancy Hanks was discovered; soon other important mines were opened, and a variable but continuous production has been maintained ever since. Although Garnet as a mining center is less widely known than it deserves, this is partly because its history happily has been free from questionable stock promotion. For the most part the mines have been made to pay their own expenses from the start, a policy that has been possible because rich ore generally extends to the surface.

Records of production since 1897 show a total of about $950,000, of which at least 95 per cent was gold and the remainder copper and silver. Considerable ore for which no records are available was mined, however, and estimates made by persons familiar with mining history of the region bring the total up to $1,400,000 or m

MINING CONDITIONS.

In 1916 the Dewey mine made fairly regular ore shipments. various reasons, of which litigation was one, the other mines w closed, but none of them is thought to be worked out. Part of ore produced in the past was milled on the ground, but most o was shipped to smelters or sampling works at Butte and Hele An extraction of 80 to 90 per cent of the gold and silver was obtai from oxidized ore worked in the Red Cloud mill by amalgamat and concentration. The shipping ore is hauled down grade 10 mi to Bearmouth and delivered to the Northern Pacific Railway or Chicago, Milwaukee & St. Paul Railway for transporting to smelters. In 1916 the cost of the wagon haul was $1.50 a ton a the railroad and smelter charges averaged about $6 addition Nearly everywhere the district contains sufficient wood and wa for ordinary mining and milling, and although snow usually cumulates to depths of 3 or 4 feet during the rather long winte mining operations are seldom interrupted.

GEOGRAPHY AND GEOLOGY.

Most of the mines around Garnet are within a mile of the tow being distributed along a rather narrow northwesterly belt that li mostly along the watershed between Clark Fork and Blackfoot Riv First Chance Gulch, noted for its large yield of placer gold, hea within the belt and leads out to the southwest. A branch of Kear Gulch drains the northwestern part, and gulches that lead to El Creek head along the north. All these gulches contained rich plac gravels. Except for the southeastern part, which includes the stee slopes south of Anderson or Bear Mountain, the mineralized belt has plateau-like surface 6,000 feet above the sea. In detail this surfac is made up of low hills and flat, shallow valleys, the landscape bein a sample of that which the whole region once presented. It i the record of a time long before the many deep, rugged valleys tha to-day dominate the region had been made. A short distance fro the divide the streams begin to flow rapidly, and soon descend int gulches 1,000 feet or more deep.

The area about Garnet is underlain by very ancient (Belt and Cambrian) sedimentary rocks, intruded by granodiorite. The oldest of these rocks, which occupy the surface from First Chance Gulch eastward, are quartzite and shale, both noticeably micaceous and schistose. Many of the layers show small dark spots or knots, and are sometimes referred to by the prospectors as "bird's-eye porphyry."

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In a few specimens that were examined under the microscope the knots proved to be either aggregates of mica or crystals of cordierite, a silicate of alumina, magnesia, and iron. In addition, there are some other secondary minerals, all going to show that the granodiorite has altered the rocks it broke through. Above the quartzite and shale lie thick and extensive beds of limestone, in which metamorphism is also shown near the granodiorite contact. Large portions of the limestone have been changed by the heat and vapors given off by the intrusive body to brown garnet rock, the most prominent outcrop of which is on the hill north of the Garnet schoolhouse. At Top o' Deep and some other localities similar garnet deposits contain copper, but those at Garnet do not, so far as known. Generally the limestone next to the contact is changed to a white marble which under the process of weathering breaks down to a sand that looks like granulated sugar. At moderate distances from the contact the rock retains its original fine texture and blue and gray colors but shows small white needles of tremolite and spots of mica. In general the evidences of contact metamorphism are noticeable for half a mile or more from the contact.

Although locally the contact plane dips toward the granodiorite, the outline of the exposed granodiorite body and its relation to other similar bodies (Pl. VI) suggest that it is larger in depth and probably is but one of several knobs on a mass that underlies a large part of the region. Small dikes of light-gray porphyry have cut the sedimentary rocks or have been forced in along their bedding planes.

The quartzite, shale, and limestone are folded together in an arch that has a northwest direction and crosses First Chance Gulch transversely, its axis lying below the Red Cloud mill. (See fig. 21, p. 191.) North of the axis there are some smaller flexures, but the general pitch of the beds is downward all the way to the granodiorite.

Faults are found in all the mines, but they can not be easily traced on the surface. Most of them have either a northeast or northwest direction, and they cause no very great displacement.

ORE DEPOSITS.

Character and distribution.—The ore bodies at Garnet are veins that in part have filled open spaces along fractures or bedding planes and in part have made room for themselves by replacing the country rock. There are three principal veins or vein systems, spaced about a quarter of a mile apart. The northernmost is a composite vein or zone of veins in granodiorite, on which are the Shamrock, Dewey, Nancy Hanks, and Cascade mines, named in order from east to west. In addition the Spokane vein is probably in the westward continuation of the zone, and the veins in the International and possibly also the Sierra seem to be parts of a fringe into which it splits on the east.

The whole zone, which for convenience is referred to as the Nancy Hanks zone of veins, is 1½ miles long. In the middle part of its course, on which are the Dewey and Nancy Hanks mines, the zone strikes about east; toward the ends it curves to the north, most strongly in that part east of the Dewey. So far as known the zone is relatively narrow, and few of the larger veins within it depart far from a dip of 30° N.

As a rule the individual veins that compose the zone do not persist in length or depth more than a few hundred feet. Each one either ends at a fault or splits into "stringers," to be succeeded by another vein a few feet to one side or the other. These characteristics are well shown in the Dewey and Shamrock workings. (See Pl. VIII and fig. 20, p. 186.) The width of the individual veins ranges from that of a mere seam to 3 or 4 feet, but most of their workable portions are from 1 to 3 feet wide.

South of the Nancy Hanks, in order, are the Magone & Anderson and Red Cloud veins, each following a bedding plane in schist or quartzite that strikes northwest and dips about 30° N. These veins are not composite like the Nancy Hanks zone, and, although as a rule not over 2 or 3 feet wide, each persists, except for interruptions by faults, a distance of half a mile or more. Two profitable mines have been opened on the Magone & Anderson vein, and the Red Cloud contains the principal ore bodies that have been worked in the First Chance Co.'s property.

Deformation.—Doubtless the fractures of the Nancy Hanks zone were originally faults and there is no apparent reason why the veins in the schist and quartzite should have selected any particular bedding planes unless those planes had been opened by faulting or similar movements. After the fracture openings were filled movements were renewed between their walls in the Nancy Hanks zone, severely crushing the ore in many places. The veins of this zone are also cut by transverse and strike faults, few of which, however, have caused displacements of more than a few feet. Available evidence indicates that the fault movements were normal—that is, the hanging wall has gone down relatively, but the scratches on the walls show that the movement was generally oblique.

Faults are less numerous in the Magone & Anderson and Red Cloud veins than in the Nancy Hanks zone, but, as a rule, the displacement on each one is greater. All the larger faults observed strike northeast, and most of them dip steeply to the northwest. One has dropped the Magone & Anderson vein 200 feet or more between the workings of the Magone & Anderson mine and those of the Grant & Hartford. Likewise, the Fourth of July vein appears to be a portion of the Red Cloud vein that was faulted down several hundred feet. Small northeast faults are numerous locally, but certain parts of the veins several hundred feet in length are practically undisturbed.

Ore shoots.—Few parts of the veins wide enough to be workable are barren. This is especially true of the middle part of the Nancy Hanks zone, where practically all the flat lenslike bodies (fig. 19) that make up the veins may be regarded as ore shoots. These bodies are generally 2 or 3 feet wide or thick and from 25 to 50 feet in breadth and length. The largest one reported, the "red-ore" shoot of the Nancy Hanks mine, is about 150 feet in stope and pitch lengths and 2 or 3 feet wide. Most of the shoots pitch slightly westward. The pinched portions which occupy about as much of the fracture openings as the swelled portions, or lenses, generally contain an inch or less of gouge or crushed ore.

As a rule, the wider parts of the Magone & Anderson and Red Cloud veins are rich enough to be considered ore.

Tenor.—Most of the ore from Garnet is rich—a condition that allows it to be shipped profitably and compensates generally for the relative narrowness of the veins. One carload of oxidized ore from the Tiger mine yielded at the rate of nearly $500 a ton, a large amount of $200 ore was produced by the Nancy Hanks, and rich shipments are reported from the Crescent and Fairview mines. The general run of the ore, however, averages much less, the lots mentioned being exceptional and obtained mainly from the oxidized zone. Sulphide ores from the Nancy Hanks zone generally run about $80 a ton, of which 80 to 90 per cent is in gold and the remainder in copper and silver. Information concerning the relative tenor of the oxidized and sulphide ores of the Magone & Anderson vein is not available. Most of the ore produced was oxidized, and the average of all the ore shipped is said to be about $60 a ton. Not including some exceptionally rich lots, the oxidized ore mined from the Red Cloud vein averaged $20 to $35 a ton, and the sulphide ore remaining is estimated by competent engineers to average between $15 and $25 a ton. In both the Magone & Anderson and the Red Cloud veins copper and silver are proportionately less abundant than in the Nancy Hanks, although this statement may not hold strictly true for the lower levels in the Red Cloud, from which some specimens rich in tetrahedrite are said to have come. Thus from north to south there appears a progressive general decrease in the richness of the ore, but the Magone & Anderson and Red Cloud veins are perhaps as profitably exploited as the Nancy Hanks, because their ore bodies are larger and more favorably situated for mining through adit levels.

Mineralogy.—Quartz generally forms 50 to 90 per cent or more of the vein material, though exceptionally it may be less in amount than the other minerals combined. Barite is widely but irregularly distributed and is generally coarse textured, showing characteristic large cleavage faces. A carbonate of calcium, magnesium, and iron, apparently the mineral ankerite, is found in many of the veins, particularly those in quartzite and schist, but it ranges in color from white to pale yellow or brown and doubtless is not of uniform composition. Calcite occurs in subordinate amounts associated with the ankerite.

The principal ore minerals are pyrite, tetrahedrite (gray copper), chalcopyrite, and galena or their oxidation products. All are widely distributed, and pyrite, as usual, is found everywhere in the veins and is generally the most abundant of the sulphide minerals. It occurs as massive, rather coarse textured aggregates and disseminated crystals and grains of various sizes. Tetrahedrite is not uniformly distributed, commonly occurring in irregular bunches, and it is rather more abundant in the Nancy Hanks zone than in the other lodes. Galena and chalcopyrite are less common than tetrahedrite and are likewise of irregular distribution.

Of somewhat rare and exceptional occurrence are tellurides of gold, silver, and bismuth, found in the Fairview mine, and molybdenite, observed in some of the mines as thin films on seams in the wall rocks.

In the oxidized zone native gold is commonly embedded in grains of limonite that were derived from pyrite. Gold inclosed in pure quartz was seen in a few specimens, one of which contained the tellurium minerals mentioned above. By far the most of the gold and part of the silver appears to have been brought into the veins and deposited with the pyrite and probably also with the chalcopyrite. The sulphides later deposited, particularly the tetrahedrite, have added some silver but practically no gold. As would be expected from the abundance of pyrite in the sulphide zone, the oxidized portions of the veins contain much limonite. Copper stains appear here and there, a little antimony ocher occurs in places, and rarely manganese stains may be seen.

Some interesting and important relations of the vein minerals to one another are very plainly shown. The first minerals that came into the veins were quartz, barite, and pyrite, all of which crystallized at the same time. Calcite and ankerite were then deposited, filling such spaces as were left by the other minerals and also making additional room for themselves by replacing the wall rocks. Chalcopyrite and a little pyrite seem to have come in later, and the tetrahedrite and galena, accompanied by new quartz, clearly were introduced last, filling small cracks in the older minerals and replacing them, particularly the pyrite. Although tetrahedrite and galena occur in the same veins, they were not seen in actual contact, and their order of deposition was not made out.

Oxidation and enrichment.—For the most part oxidation is partial or complete down to a surface that rises gradually away from the natural drainage lines. In the immediate vicinity of Garnet the greatest depth of oxidized ore is about 75 feet. Farther away, where the gulches are deeper, oxidation may descend 200 or 300 feet. As usual, however, grains of the sulphides completely surrounded by quartz may be found anywhere, even at the surface. The oxidized ore is porous, generally consisting of "honeycomb" quartz and earthy iron oxides. As a rule it is two or three times as rich in gold as the corresponding sulphide ore below, a condition brought about by the solution and removal of valueless material. On the other hand, it has lost more or less of the copper, lead, and silver, which have been leached out and either scattered or carried below. No downward enrichment of any importance seems to have taken place, however.

Genesis and conclusions.—The veins as described are similar to those generally regarded as the effects of granitic intrusion. Their mineralogy and geologic relations suggest that they were formed at moderate to shallow depths by heated solutions given off from the granodiorite. The later generation of minerals, which includes the tetrahedrite, is doubtless related to a younger variety of the granodiorite or possibly to some other intrusive body not exposed at the surface. In any event the minerals came from below—a fact that warrants belief in the persistence of good ore below the limits of the present workings. At Coloma, 2½ miles away, there is some evidence to indicate that veins situated similarly to the Nancy Hanks become lean in gold at a depth of about 700 feet below the general summit level. Whether or not the veins at both places were formed under exactly the same conditions can not be said, but the localities are near together and doubtless their histories are not very dissimilar. These veins are in granodiorite. The veins in quartzite and schist were probably formed under different conditions, being apparently farther away from the source of their minerals and probably not subject to the same limitations. These considerations do not apply to the tetrahedrite and the other minerals of a late generation, which for all that could be learned may continue downward indefinitely.

Whether or not copper will become more abundant in depth is an interesting speculation. In the mines that have the most complete records slight increases in copper are generally shown in ore from the lower levels, but this may be due to the fact that shipments from the higher levels contained oxidized ore.

Although the veins at Garnet are too small to warrant large capitalization or heavy investments in advance explorations, new work on a larger scale than heretofore may be undertaken with reasonable confidence. Considerable parts of the veins within the general area of rich mineralization, particularly the Nancy Hanks zone, are unexplored beyond shallow depths. Several claims at Garnet that were not examined are in or near the mineral-bearing area, and some of them will doubtless be developed into productive mines in the future. In the light of all that was learned the opinion is ventured that the Garnet district will continue to be productive for a long time.

MINES AND PROSPECTS.

J. L. TEMPLEMAN CO.

A group of mines that includes the Dewey, Tiger, Nancy Hanks, Cascade, and Spokane is (September, 1916) under bond and lease to J. L. Templeman and others, who have operated the Dewey continuously since February, 1915. Except the Tiger, the mines named are along the Nancy Hanks zone or vein system, a single vein or zone of closely related veins that extends from the town of Garnet westward a mile or more.

Dewey.

The Dewey mine is on the gentle slope west of Williams Gulch, about a quarter of a mile northwest of the main part of the town of Garnet. During 1915 and 1916 it was operated under the direction of J. G. Klenze and produced, in round figures, $100,000 gross. Gold contributed slightly more than nine-tenths of this sum, and copper and silver about equal portions of the remainder. The ore was shipped to the Washoe sampler at Butte, and yielded an average of $74 a ton.

Prior to 1915 the Dewey was worked by S. I. Ritchey and others, and contributed largely to the prosperity of the camp. The amount of this early production, whatever it may be, is included in the total given for the Nancy Hanks.

The principal workings are an incline 400 feet deep that slopes northward at an average angle of 47°, and several levels that aggregate 1,000 feet or more (Pl. VIII, p. 186); the lowest, or "400 level," is about 275 feet vertically below the surface. Underground connections are made with a shaft 200 feet to the east and with the Nancy Hanks workings, about an equal distance to the west.

The Dewey vein has an average strike of N. 75° E. and a dip of about 35° N. It shows no signs of failing at a depth on the slope of 400 feet and probably extends a long distance along the strike. Owing to displacements by faults and the limits of the development workings the vein is difficult to identify as an individual fracture for more than 200 feet east of the incline. To the west, however, it is said to be identical with the Nancy Hanks vein. In width the vein ranges from a mere seam to 3 or 4 feet. It consists of a series of connected irregular, flat lenses, of which the principal ones are from 25 to 50 feet in diameter and average 2 or 3 feet in thickness. The walls are well defined and lined with a soft gouge that permits the vein rock to be readily separated from them. On the 400 level 90 feet east of the incline the vein splits into several stringers and becomes lean.

Fault movements since the vein was formed have been widespread and severe, but most of them have taken place parallel to the plane of the vein and have therefore not shifted it. Nearly everywhere the vein shows some effects of squeezing; in places it is crushed to a fine sand and its component minerals ground together. (See fig. 17.) Apparently the pinched or narrowed portions are largely the result of movement of the walls under pressure. To a considerable distance from the vein the wall rocks themselves are more or less crushed or schistose and cut by networks of curved fractures and slips. There are also some larger faults and fault zones, the principal ones of which strike about parallel with the vein but dip more steeply. Those that cut the vein, however, displace it but a few feet, and the fault movement appears to have varied from place to place or to have been shifted from one fracture to another. Other faults that show a wider range in strike and dip cross the vein, but the dislocations they have caused are generally trifling.

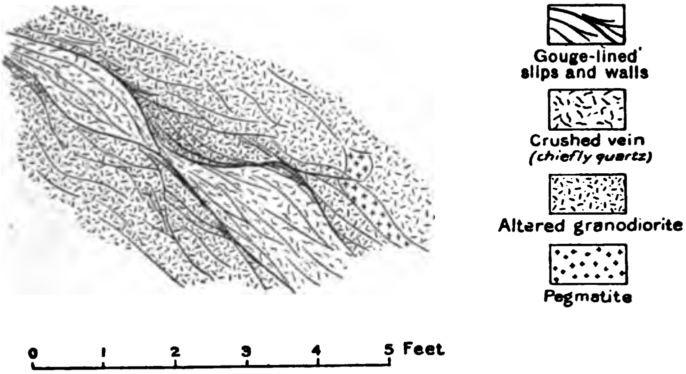


FIGURE 17.—Vein in 400 level west, Dewey mine, Garnet Range, Mont.

Next to the vein the walls have been altered to a greenish-gray rock softer than the fresh granodiorite and scantily sprinkled with fine grains of pyrite. Under the microscope the lime-soda feldspars are seen to be almost wholly changed to sericite, chlorite, and calcite, parts of the rims only remaining fresh. The orthoclase is also partly decomposed, and the hornblende is completely changed to a fine-grained material in which chlorite is abundant.

The gouge that lines the vein walls is generally less than an inch thick and is composed chiefly of sericite and finely crushed ore. It ranges from light gray to dark greenish gray in color, a dark shade generally indicating a considerable amount of ground-up sulphides.

Where the vein has not lost its original features it shows a banded structure rather plainly (fig. 18), being commonly made up of two or more layers separated by thin dark partings that in places swell into small lenses or "horses" of country rock. The texture of the vein minerals is rather coarse, crystal faces or cleavage planes an inch or two across being common. In places the crystalline structure is at right angles to the walls, showing that open spaces have been filled. Commonly, however, the structure shows no definite arrangement except the faint outlines of masses of wall rock that have been replaced by the vein minerals. The gangue and ore minerals are all more or less intermingled, but usually the sulphides are concentrated in the middle of the vein or in one of its layers (fig. 18).

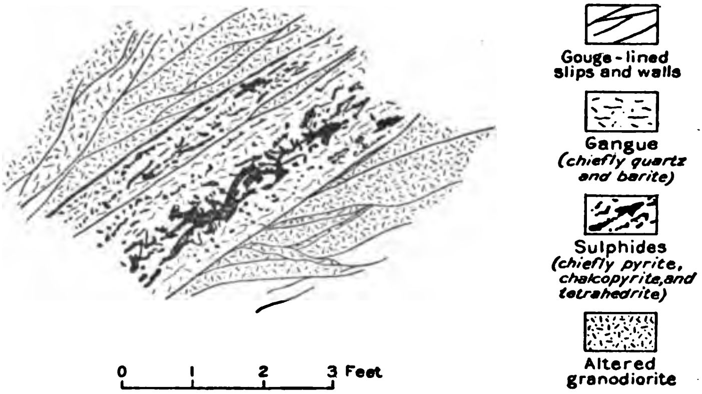

Gouge-lined slips and walls
Gangue (chiefly quartz and barite)
Sulphides (chiefly pyrite, chalcopyrite, and tetrahedrite)
Altered granodiorite
0 1 2 3 Feet

FIGURE 18.—Vein in 400 level east, Dewey mine, Garnet Range, Mont.

In the lower levels the vein consists of quartz and barite (heavy spar), together with the ore minerals pyrite, tetrahedrite (gray copper), and chalcopyrite, named in the general order of abundance. The quartz, barite, and pyrite are intergrown and are the first minerals that formed in the vein. Quartz is the most abundant, making up generally about nine-tenths of the vein and in few places less than half. The barite forms coarse tabular crystals but is irregular in distribution, being absent for considerable distances. The pyrite is widely distributed as grains and "cubes" of various sizes, the largest an inch across, some of which are completely inclosed by quartz crystals. Chalcopyrite was introduced later; it replaces pyrite in part, fills small cracks in the barite, and is of sparse and irregular distribution. Tetrahedrite, which is of wide but irregular occurrence, replaces both pyrite and chalcopyrite and with the possible exception of galena was the last mineral that came into the vein. Galena was seen in ore from the Nancy Hanks workings and is said to have been found in the Dewey also. In ore from the Red Cloud mine it was observed to have replaced chalcopyrite, but nowhere was its age relation to tetrahedrite discovered. Molybdenite was seen as thin films on slips in the wall rock along the side of the vein but not within the vein itself.

Above the 100 level the Dewey vein is partly or wholly oxidized. Limonite (hydrated iron oxide) is, as usual, the most abundant of the secondary products, copper stains are rather scanty, and manganese occurs in traces only.

Practically all of the vein that is exposed in the Dewey workings has proved to be ore, but the lenses are generally richer than the pinches. Considered together the lenses that have been worked in the Dewey form an irregular ore shoot that extends from a point near the surface down 400 feet and to an unknown distance farther. It ranges from 80 to 130 feet in width and has a slight general westward pitch.

The ore extracted so far has contained on the average a little more than 3½ ounces of gold and 6½ ounces of silver to the ton and 2 per cent of copper. In the different carload lots the gold ranges from 1½ to nearly 5 ounces to the ton, but these extremes are not common. Silver likewise holds rather steadily to the average, rarely showing as much variation as 6 ounces to the ton. Taken in the order of shipment, which is said to correspond with the progress of mining from higher to lower levels, the ore shows steady and strong increases in gold and silver down about halfway, beyond which there is little or no change—certainly no diminution. There is close correspondence between the variations in gold and silver content, an increase or decrease in one being followed by a proportionate change in the other.

Copper ranges between 0.5 and 4 per cent, being somewhat erratic locally but showing a general increase with depth. There is absolutely no relation between the variation in tenor of copper and gold, but the records of the adjoining Nancy Hanks mine and assays of specimens from the Dewey that are especially rich in tetrahedrite show that marked increases in the amount of copper are promptly followed by an increase in silver. Neither gold nor silver in the free state is visible in the sulphide ore, but in the oxidized ore, particularly that of the Nancy Hanks and Cascade mines, native gold occurs in iron oxides that were derived at least in part from the oxidation of pyrite. The conclusion is plain that the gold and part of the silver, together with the pyrite, were introduced into the vein before the tetrahedrite.

Whether or not the replacement of pyrite by tetrahedrite has been accompanied by a migration of gold to some other part of the vein is an interesting question that can not be answered at present. If this has happened, however, a decrease in gold may occur in depth should the tetrahedrite increase, but the value of the additional copper would doubtless offset the decrease in gold and the ore would continue to be at least as valuable as it was before.

Nancy Hanks.

The town of Garnet was first brought into prominence by the discovery of a rich ore shoot in the Nancy Hanks vein in the workings known as the "old shaft," about a third of a mile northwest of the town. Uncommonly rich placer deposits in Williams Gulch were mined clear up to the inconspicuous outcrop of the vein, which is said to have been discovered and located by S. I. Ritchey in 1874. No great amount of development work was done, however, until 1896, the year of the "rich strike" of ore. During the next three years the mine produced shipping ore continuously, and thereafter it yielded intermittently until 1907. Except for a little gouging here and there by lessees, the mine has been idle for the last 8 or 10 years, and the workings are out of repair.

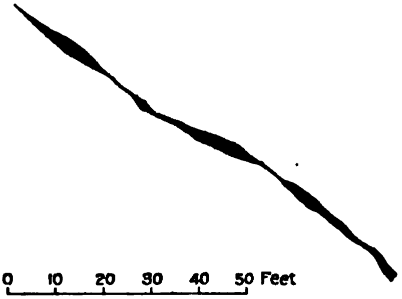
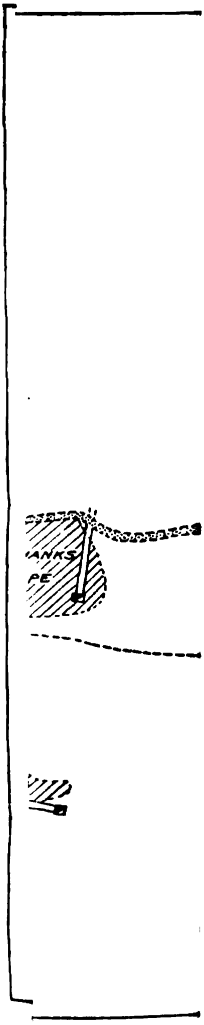


FIGURE 19.—Diagrammatic section of Nancy Hanks vein, Garnet Range, Mont.

Incomplete records of production, which include some ore taken from the Dewey prior to 1915, aggregate nearly $300,000. Nine-tenths or more of this sum was in gold and the remainder in copper and silver. The value of the ore ranged from about $40 to $200 or more a ton, but most of the shipments did not vary greatly from $92, the average.

Shafts were sunk 100 feet deep or more at two points. One, the "old shaft," is about 200 feet west of the Dewey incline and penetrates the same or a very closely related vein. The other, the Minnie Palmer shaft, is 500 feet farther west, on the projected continuation of the vein worked in the old shaft. Between the shafts there are several surface workings, all more or less caved, and at a depth of about 100 feet drifts were run east and west from the old shaft and west from the Minnie Palmer shaft, the principal stopes being above these levels. (See Pl. VII and fig. 19.)

Most of the Nancy Hanks production came from stopes west of the old shaft. The locally celebrated "red ore" shoot extended from a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point near the surface to the 65-foot level on a slope of 25° and is said to have yielded gold at the rate of $200 or more to the ton. At least half of the total production of the mine is estimated to have come from this shoot, which is described as a tabular body 165 feet long and from 1 to 3 feet thick, pitching slightly westward. It pinched out below, and explorations are said to have ceased a few feet beyond its point of disappearance. From the west drift at the Minnie Palmer shaft a rich ore body 1 to 3 feet thick was stoped for a length of 50 feet and a height of 13 feet.

The dimensions of other ore bodies worked from the old shaft were not ascertained. The operators are said to have been discouraged from deeper explorations by the idea prevalent at the time that the ore bodies were superficial and that the first pinch ended the vein. Recent developments in the Dewey, however, give strong encouragement for deeper exploration along the whole vein system.

Although there was no opportunity to study the Nancy Hanks ore in place, much of interest was learned from the dumps and the smelter records. Ore fragments on the dump of the old shaft are similar to ore from various levels of the Dewey. Quartz is the most abundant gangue mineral. Barite is generally present, and some of the oxidized ore shows tabular cavities from which calcite or ankerite was leached. In general the oxidized ore shows abundant limonite, both as earth masses and as "cubes" after pyrite. There are also some green and blue copper carbonates, a little antimony ocher, and rarely a little manganese stain. In the sulphide ore pyrite and tetrahedrite are abundant and chalcopyrite subordinate. Galena occurs in some specimens, filling cracks and cavities in the quartz and replacing pyrite. The tetrahedrite of the Nancy Hanks ore, like that in the Dewey, replaces the other sulphides except galena, to which its relations could not be made out. Some of the ore is distinctly banded, showing a replacement of the wall rocks.

Except local bunches of limestone that occur as inclusions, the wall rock of the Nancy Hanks vein is granodiorite, altered similarly to that of the Dewey. The limestone inclusions are dolomitic, have been recrystallized, and are streaked green with chlorite. They are also cut by veinlets of secondary calcite which contain a little pyrite and galena. Ore from the Minnie Palmer shaft shows pyrite, chalcopyrite, and tetrahedrite, named in the order of their genesis. Fine particles of gold are visible in the limonite of the oxidized ore, particularly the cubelike grains derived from pyrite.

Smelter returns from carload lots of the Nancy Hanks ore give the history of the mine in a general way from 1897 to 1903. For a time the ore ran about 8 ounces of gold to a ton and but a trace of copper. This represents the bonanza "red ore" shoot. As is to be expected in oxidized ores, the silver was variable, ranging from 4 to 28 ounces a ton. Then followed a few rather lean shipments that doubtless represent gleanings from the dumps and stopes, succeeded by shipments, probably in part from the Dewey, that show the gold reduced by half but some copper always present and the silver less variable than before. In general the copper was 3 or 4 per cent, the silver about 10 ounces to the ton, and the gold about 4 ounces. Some of the lots contained from 5 to 12 per cent of copper. Invariably these lots show increases in silver that range from 4 to 18 ounces to the ton, and many but not all of them show a marked falling off in gold. After 1899 there were intermittent shipments that show many fluctuations in value and are said to be made up of the ore searched out here and there from the dumps and stopes by lessees. No separate record of ore taken from the Minnie Palmer shaft is available, but some of it is said to have been of very high grade. Ton for ton there was about twice as much gold in the red ore as in the sulphide ore, a condition doubtless caused by the oxidation of the heavy sulphide minerals and the leaching away of valueless material. There is no evidence to suggest that the gold was increased by downward enrichment.

Little or no exploration is understood to have been done in the Nancy Hanks below a depth of 100 feet, and some portions of the vein are hardly opened below the surface. That other ore shoots are to be found is but a reasonable inference, considering the persistence of the vein or zone, the large part of it that is unexplored, especially in depth, and the fact, as shown by the Dewey, that deep as well as superficial ore bodies exist.

Cascade.

The Cascade mine is in a basin at the head of Kearns Gulch about three-quarters of a mile west-northwest of Garnet and half a mile west of the Nancy Hanks. About $6,000 worth of ore is said to have been produced from stopes above the upper tunnel and pits along the outcrop. In 1916, under a lease, some development work was being done by S. I. Ritchey in an east drift from the lower tunnel. The principal workings are two adit levels (Pl. VII), at elevations of 5,870 and 5,950 feet above the sea, that correspond respectively in height with the 300 and 150 foot levels in the Dewey. The lower adit is driven southward 400 feet in granodiorite, and 50 feet in limestone and after crossing a dike of granodiorite ends in shale. An east drift 300 feet long in part follows the dike, and a west drift leaves the adit 100 feet nearer the portal, goes through granodiorite, and ends in limestone. On the surface, above, granodiorite only is exposed, therefore the limestone and shale penetrated below are regarded as fragments suspended in the intrusive body. The limestone is coarsely recrystallized and streaked and stained green with chlorite.

Along the west drift there is a vein from 2 to 18 inches in width that has yielded a little rather lean ore but is not persistent and is for the most part filled with barren-looking quartz. The vein strikes N. 65° W. and dips 30°–40° N., and the quartz is badly crushed in places by postmineral movement.

At the face of the east drift in granodiorite there is a vein that strikes N. 75° W., pitches steeply north, and carries 18 inches of good-looking ore. The footwall is well defined, but the north or hanging wall is so extensively altered and cut by quartz stringers that it is difficult to separate country rock from the vein. The granitic texture of the altered rock is faintly preserved, but its original minerals have been largely replaced by sericite and quartz, and it contains a little pyrite and iron oxides and a greenish-yellow stain that is probably copiapite, a hydrated sulphate of iron. At a distance of 4 feet limestone comes in beyond a slip that is parallel with the vein.

The ore consists of rather coarse vein quartz that contains scattered grains of pyrite, chalcopyrite, and tetrahedrite, most of which are partly or wholly oxidized. The tetrahedrite fills cracks and cavities in quartz and penetrates chalcopyrite in a network of veinlets. Fine particles of gold can be seen in the oxidized pyrite or "cube iron," and the ore is evidently of good grade. Small amounts of malachite and chrysocolla occur in cracks and cavities.

The upper tunnel was not entered. Its dump and those of some shallow workings along the outcrop show fragments of ore similar to that in the lower tunnel except that it is completely oxidized. Many of the limonite pseudomorphs, or grains of "cube iron," as they are generally known, preserve perfectly the crystal form of pyrite, even showing fine striations. The fact that gold occurs rather generally in these pseudomorphs and is rarely seen in other associations is strong evidence that it was brought into the vein with the pyrite. "Cube iron" is generally considered a trustworthy indication of good ore in the Garnet district.

Spokane.

The Spokane mine is in a shallow basin at the head of Kearns Gulch, about a mile northwest of Garnet and half a mile beyond the Cascade. A small production of rich ore similar to that of the Cascade and estimated to have yielded $3,000 is reported. The workings were not accessible for examination in 1916, but the vein is said to strike a little west of north and to dip 60° N. Its position and alignment suggest it to be a part of the Nancy Hanks vein system.

SHAMROCK.

The Shamrock mine is on the east side of Williams Gulch opposite the Dewey and about 600 feet distant. It was closed in 1916 and had not been operated for two or three years, the last work having been done by lessees. No certificates of ore shipments were seen, but a production of more than $100,000 is reported. The workings were not entered, but their details, including the geology, are shown by some excellent maps made for former operators by Billingsley & Grimes. The entry is an incline 350 feet deep on a slope of 32°, and the levels aggregate 1,200 feet or more in length. (See Pl. VIII.) A branching vein with an average northeast strike has produced ore similar to that of the Dewey. It is clearly a continuation of the same belt of fractures to which the Dewey belongs, although the particular vein worked in each is probably not the same. To the northeast the Shamrock vein, like the Dewey, on the 400 level east, shows a tendency to "stringer out." Faults, the largest of which is nearly parallel to the vein in strike but pitches more steeply, displace the vein a few feet. (See fig. 20.)

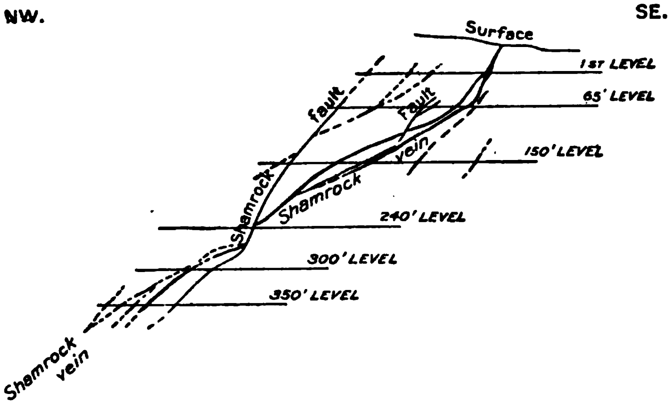
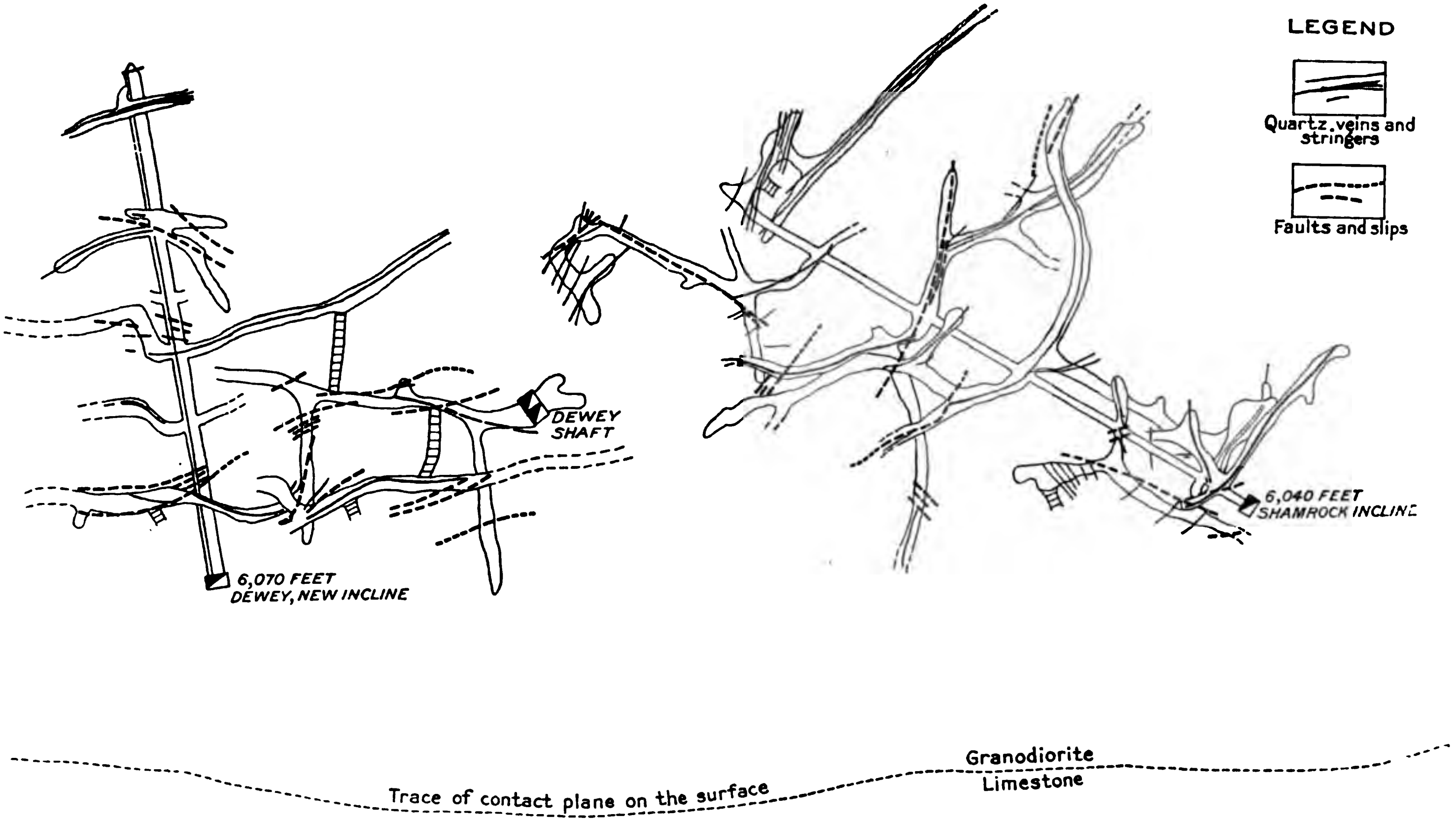


FIGURE 20.—Cross section of Shamrock mine, Garnet Range, Mont.

INTERNATIONAL.

The International mine is about a quarter of a mile north of the center of Garnet and adjoins the Shamrock on the east. It is developed by a shaft reported to be 100 feet deep and by levels that were not accessible for examination in August, 1916.

Two or more small veins that have a northeast strike parallel with the Shamrock are reported to have been developed and to have yielded rich oxidized ore. Smelter certificates of intermittent shipments during the period 1910–1914 amount to about $9,000. The gold content ranged generally from 4 to 8 ounces and the silver from



STRUCTURE IN THE SHAMROCK AND DEWEY MINES, GARNET RANGE, MONT.

Scale 100 feet to 1 inch.

5 to 10 ounces a ton. Copper was absent from some shipments and present in very small amounts only in the others.

A specimen of ore from the International shows flake or leaf gold embedded in limonite.

TIGER.

The Tiger mine, a quarter of a mile west of Garnet and a short distance south of the Nancy Hanks, is developed by several short inclines and open cuts, only portions of which were examined. The formation is limestone, that has been recrystallized to a rather coarse white marble and in places changed to garnet rock and hornstone by the heat and vapors given off by the adjacent granodiorite body. Smelter returns, said to be incomplete, show a production of $23,000. One carload that averaged 22½ ounces of gold and 25 ounces of silver a ton was the richest single shipment made from the camp. Persons familiar with the mine estimate its total production at $40,000.

The ore bodies occur along a fracture that strikes north-northeast, dips west at a low angle, and is not known to continue beyond the contact into the granodiorite. The owners' maps show the outlines of the stopes (Pl. VII, p. 182), which are said to have been irregular in width but generally narrow. No specimens of the ore were seen, but it is said to be oxidized and similar in appearance to that from the "red ore" shoot of the Nancy Hanks. At a depth of about 90 feet the ore is said to have ended at a broken zone or fault having a northeast trend.

SIERRA.

A small production of medium-grade ore is reported from the Sierra mine, half a mile north of Garnet, in the granodiorite area. The workings consist of two adits and an incline, said to be 280 feet deep, only the upper portion of which was accessible in 1916. The vein strikes north, dips 30° W., is 1 to 2 feet wide, and extends at least 500 feet horizontally but is said to be pinched out in depth. Oxidized ore only was seen in the upper workings, but considerable sulphide ore that probably came from the deeper levels is scattered over the dumps. In general, this ore consists of coarse-textured quartz, calcite, and either ankerite or a similar mixture of the carbonates of calcium, magnesium, and iron, together with pyrite and tetrahedrite. As is usual in the district, the tetrahedrite replaces the pyrite in part and is the youngest of the vein minerals that were introduced from below. The oxidized ore contains much limonite and a little copper stain.

GRANT & HARTFORD.

The Grant & Hartford mine is a quarter of a mile south of Garnet, the stage road down First Chance Gulch passing under the trestle that supports the car track between the main adit level and its dump. In addition to this working, which extends eastward into the Magone & Anderson ground (Pl. IX), there is a winze, with short levels, said to be sunk 200 feet on the vein, and an adit level on the west side of the gulch, none of which was accessible for examination in 1916. Most of this work was done prior to 1910, and a production estimated at $30,000 is said to have come mainly from the winze levels. During 1912 and 1913 the main adit was used for extracting ore from the Magone & Anderson mine.

The country rock is quartzite and schist that strike about east, have an average dip of 30° N., and show abundant fine mica and small knots that under the microscope prove to be cordierite. Except where it cuts across a small dike of granodiorite the vein occupies a bedding plane and ranges from 6 inches to 2 feet in width. Beyond 200 feet from the portal of the main adit the vein is lost in a northeasterly fault zone, but it reappears farther east in the Magone & Anderson zone.

In the main adit level the vein is composed of quartz, barite, ankerite, calcite, and pyrite, or its oxidation products. The pyrite is disseminated irregularly but in places is massed in the middle or on one side of the vein to a thickness of several inches.

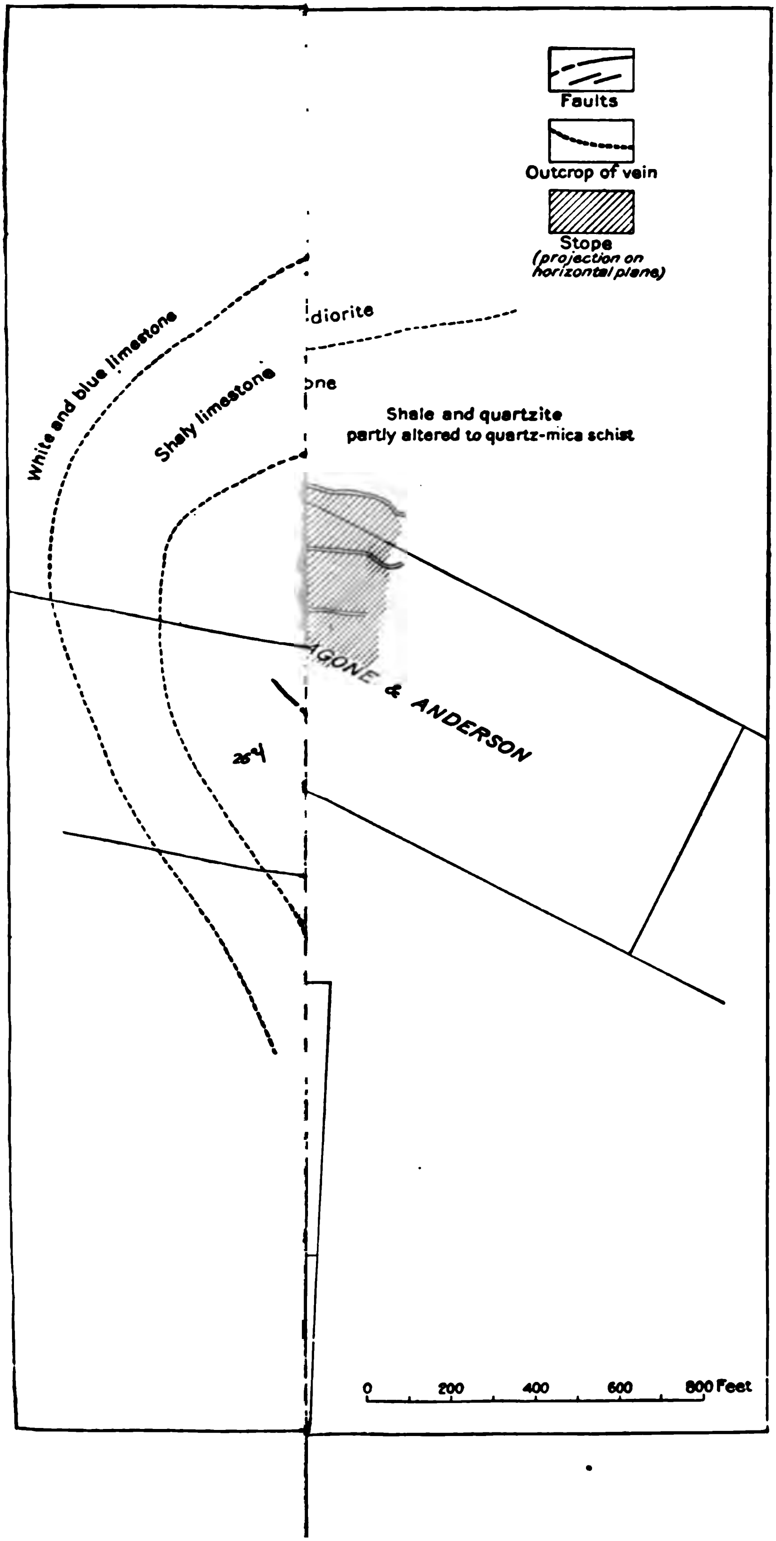
Oxidized ore from small stopes above the main level is said to have contained from 1½ to 5 ounces of gold and about an equal amount of silver to the ton. From the winze levels sulphide ore of about the same tenor is said to have been obtained, the shape of the ore bodies being that of small flat lenses 3 feet in maximum thickness.

Locally the wall rock is replaced by ankerite and calcite, and fine grains of pyrite are generally distributed through it.

MAGONE & ANDERSON.

The Magone & Anderson mine is east of the Grant & Hartford and about a quarter of a mile southeast of Garnet. Considerable work was done on this property before 1910, but its most productive period was the three years following.

Incomplete records show about 2,600 tons of ore are shipped that is said to have averaged $60 a ton, making a total of over $150,000. In addition about $15,000 worth of ore, said to have been mainly sorted from the dumps, was shipped in 1914, and persons familiar with the mine estimate its total yield at $300,000 or more. Smelter certificates for the 1914 shipments show from half an ounce to 5½


Faults
Outcrop of vein
Stope
(projection on horizontal plane)
diorite
one
Shale and quartzite
partly altered to quartz-mica schist
White and blue limestone
Shaly limestone
GONE & ANDERSON
26°
0
200
400
600
800 Feet

ounces of gold and one-tenth of an ounce to 6¼ ounces of silver to the ton. Most of the lots contained a little copper, generally less than 1 per cent.

The main adit level of the Grant & Hartford mine extends east into the Magone & Anderson ground 1,000 feet or more and was used as the main working entry for that property during its later period of activity. At a level about 80 feet higher there is a cross cut known as the Magone & Anderson tunnel No. 5, driven south 600 feet to the vein. There are drifts from No. 5, and the vein has also been worked through several higher adit levels.

The country rock is of the same character and structure as in the Grant & Hartford. Tunnel No. 5 begins in granodiorite and passes through a contact shatter zone 100 feet wide, in which the schist is broken into angular blocks of various sizes wedged apart by dikes of the intrusive rock. To a considerable distance beyond this zone the rocks are intensely metamorphosed, but their sedimentary origin is plainly evident.

Throughout the Magone & Anderson ground the vein lies in a bedding plane which strikes, in general, a little north of west and dips about 30° N. Except that its continuity is interrupted by a fault zone near the west end of the Magone & Anderson claim, the vein is known to persist for a horizontal distance of at least 1,500 feet. The lowest working in the vein is the Grant & Hartford winze, 200 feet below the creek. Levels carried into the Magone & Anderson ground from the Grant & Hartford tunnel reach a depth, measured on the dip of the vein, of 500 feet below the surface.

The fault zone, which has a width of 100 feet or more, crosses the vein obliquely from southwest to northeast and shifts it to the north. The principal slip planes pitch from 35° to 75° NW. and are lined with thick layers of gouge, and altogether the horizontal displacement of the vein at any given level amounts to about 200 feet.

East of the fault zone is a series of stopes on lenses that are connected by narrow or lean portions of the vein; considered together the lenses form a thin tabular body from 100 to 300 feet in stope length and 500 feet in pitch length.

The vein filling normally consists of quartz, barite, ankerite, and calcite in varying proportions, through which grains and masses of sulphide minerals are scattered. A banded structure is common, showing partial or complete replacement of schist by the vein minerals. Pyrite, which occurs as crystals and irregular grains intergrown with the quartz, is the most abundant sulphide. Tetrahedrite is rather sparingly and irregularly distributed, and without exception has replaced pyrite or some other vein mineral.

The lower limit of oxidation rises very slowly eastward, the bulk of the ore above the creek level being partly or wholly oxidized.

FIRST CHANCE MINING CO.

Several claims about half a mile south of Garnet that have been worked by the First Chance Mining Co. are generally known as the Mitchell & Mussigbrod mines. The most extensive workings are on the Red Cloud and Lead King claims, situated, respectively, on the east and west sides of First Chance Gulch. A large amount of work has also been done on the Crescent, Fairview, Fourth of July, and several other claims.

On the stage road from Bearmouth to Garnet the Lead King is the first quartz mine to be seen, the dumps from its several adit levels forming conspicuous long slides on the slope above the stream.

As early as 1867, when placer mining yet dominated all activity in this district, the Lead King-Red Cloud vein is said to have been discovered, but for several years thereafter little work was done upon it. During a period of 8 or 10 years, beginning in 1897, the vein was energetically developed under the direction of Dr. Peter S. Mussigbrod, and a large quantity of ore was produced, part of which was milled on the ground and the remainder shipped to smelters. Because of litigation the property has been idle the last few years.

Mill and smelter records for the period 1898–1907 show a production of $350,000, 97 per cent of which represents the value of the gold and the remainder the silver. In addition a large amount of ore for which no records are available is said to have been extracted by lessees from the Crescent and other claims, and the owners estimate a total yield of $500,000. The company's mill in First Chance Gulch close to the mouth of the Red Cloud incline is equipped with 10 stamps, plates, vanners, and concentrating tables.

Red Cloud.

The Crescent, Lead King, and Red Cloud mines are on a single vein which for convenience is referred to as the Red Cloud vein. This vein has been more extensively and systematically developed than others in the district and has produced at least five-sixths of the total accredited to the First Chance Mining Co. First Chance Creek has cut a deep notch across the vein, exposing a considerable portion of it to mining through adit levels. On the west slope of the gulch, in the Lead King and Crescent claims, there are seven adit levels (Pl. IX) that range from 600 to 1,000 feet in length and are distributed through a vertical distance of 300 feet measured from the stream bed. On the east slope in the Red Cloud claim there are four long adits and in addition several levels run from an incline sunk 250 feet below the stream.

The country rock consists of quartzite and schist that commonly show small dark oval spots caused by groups of mica flakes or crystals of cordierite. Small dikes of a fine-grained gray porphyry have intruded the schist here and there; one in the hanging wall parallel to the vein is exposed in Lead King mine. Under the microscope specimens from some of these dikes show the composition of granodiorite porphyry, and to the unaided eye all appear much the same. The quartzite and schist are folded in an arch (fig. 21), the axis of which crosses First Chance Gulch about 500 feet south of the mill.

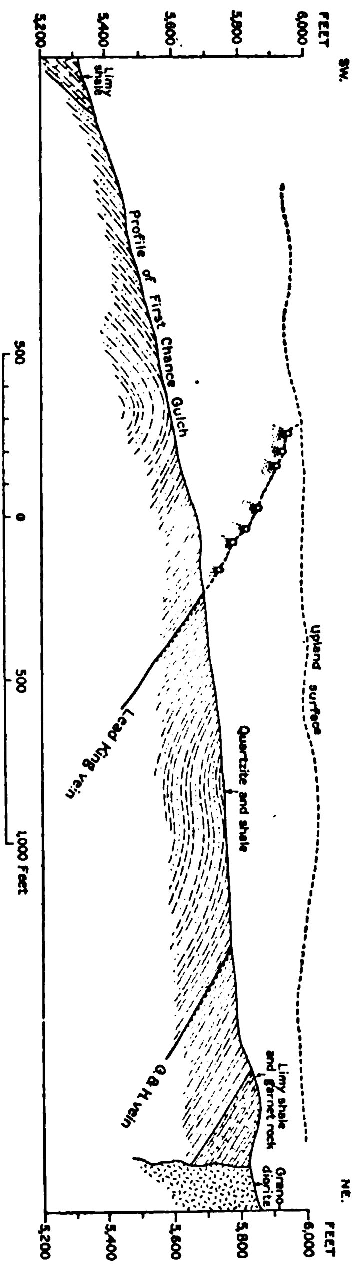


FIGURE 21.—Section along First Chance Gulch, Garnet Range, Mont.

The Red Cloud vein lies along a bedding plane and except for slight interruptions by faults is known to persist half a mile along the strike and at least 800 feet on the dip. In the Lead King workings its average strike is about N. 50° W., and in the Red Cloud about N. 70° W., and the dip ranges from 25° to 35° NE. Its thickness ranges from that of a mere seam to 3 or 4 feet, considerable portions averaging 2 feet or more.

There are two main ore shoots or groups of ore shoots about 700 feet apart, one on each side of the creek, the intervening portion of the vein being either pinched and lean or broken by faults. The shoot on the west claims has a stope length of 500 to 700 feet or more and comes to the surface west of the mouth in the Lead King and Crescent of adit No. 4 (Pl. IX). In the adits that were accessible for examination, namely, Nos. 1 and 2 and part of No. 3, the ore body in few places is less than a foot wide and for the most part ranges between 1 and 3 feet. Levels below adit No. 1 have not been driven far enough to reach this ore shoot. In the Red Cloud claim, east of the creek, the vein swells to another large composite ore shoot that for the most part is worked out above level No. 2 east from the incline. Only parts of the workings on the east side of the gulch were entered. In Red Cloud adit No. 3, which is at about the same elevation as No. 4 of the Lead King, the vein is generally from 1 to 3 feet wide but in places is pinched to a stringer. Several stopes are carried almost to the surface, and the ore body considered in detail is made up of several flat lenslike masses and small fault blocks.

Three northeasterly faults were seen in the Red Cloud workings (Pl. IX). They dip steeply northwest, and each has shifted the vein northward from 20 to 40 feet. In adit No. 3 the first fault is 100 feet from the portal, and for the next 30 feet the rocks are more or less crushed. The principal plane in this zone strikes N. 45° E., dips 80° NW., and carries 1 foot of gouge and breccia. Another plane has a strike of N. 50° E. and a dip of 75° SE. As the movement was normal on both—that is, the hanging wall dropped—the vein was shifted first to the left and then to the right. At about 400 and 600 feet from the portal of No. 3 the vein is cut by other northeast faults that pitch steeply northwest and shift the vein to the north. Several faults parallel to those mentioned are reported to occur in the levels east from the incline, where they collectively form a fault zone 200 feet wide.

Oxidation is practically complete in the Red Cloud adit levels and above No. 4 of the Lead King. Partial oxidation is shown in the outer portions of Nos. 2 and 3, the lower limit rising slowly from the creek level as the hill is entered.

Most of the Red Cloud vein seen is composed of two or more layers separated by thin greenish-gray partings, and each layer commonly has a banded structure caused by a parallel arrangement of its minerals. In places the partings swell into small horses of country rock, and in general the vein appears to have replaced the schist rather than to have filled open spaces. Under the microscope replacement by quartz is clearly shown, fine flakes of mica arranged in parallel bands that represent bedding planes being all that remains of the original schist.

The walls are smooth and well defined and generally bear a thin soft gouge composed of very fine mica and crushed ore mixed together. Postmineral movements in the plane of the vein have not been extensive.

The vein filling normally consists of quartz with varying amounts of irregularly distributed barite, ankerite, and the ore minerals pyrite, chalcopyrite, tetrahedrite, and galena. In the oxidized zone iron oxides replace the sulphide minerals, and free gold is present. Quartz, barite, and pyrite were first introduced in the vein, followed by ankerite, or calcite, chalcopyrite, and galena or tetrahedrite in the order given. The relations of galena and tetrahedrite to each other were not made out, but both replace the other vein minerals, particularly pyrite and chalcopyrite. Except in the completely oxidized portions of the vein, pyrite occurs everywhere as disseminated grains and crystals, inclosed in the quartz or carbonate. Chalcopyrite was seen only in specimens from the lowest levels. In most of the levels tetrahedrite and galena are rather sparingly and irregularly distributed, but locally they are abundant.

In specimens of oxidized ore from the Crescent mine gold is inclosed in both quartz and limonite, occurring as flakes and ragged rough particles, some of which are fairly coarse. Flakes of gold were also seen in iron-stained ore from the upper levels in the Red Cloud claim. In the Red Cloud, as in the Nancy Hanks vein, the distribution of the gold appears to be independent of tetrahedrite or galena but closely related to pyrite. Molybdenite was seen as thin films on cleavage planes in the walls but not within the vein itself. In addition to a widespread stain and masses of earthy texture, limonite forms cubes after pyrite, the oxidized ore closely resembling that from the Cascade mine. Manganese appears to be very rare. In a few places only recent stains of manganese oxide were seen on seams in the walls.

Near the vein the wall rocks contain fine grains of pyrite and are generally bleached, showing pale-green tints. Microscopic examination of a few specimens shows their original constituents to have been partly replaced by calcite and sericite. In the granodiorite porphyry dike that parallels the vein in the Lead King adits the feldspar is almost wholly altered to sericite.

Most of the ore stoped from the Red Cloud levels was worked in the company's mill and a saving of 80 to 90 per cent effected by plates and concentrators. On the average the ore contained about 90 per cent of silica, 4 per cent of iron in the forms of pyrite and limonite, 3 per cent of sulphur, small amounts of copper and lead, and 1 ounce of gold and 1½ ounces of silver to the ton. The concentrates, which were chiefly pyrite, generally assayed from 4 to 8 ounces of gold to the ton, and half again as much silver. The bullion from the plates varied considerably in fineness, owing to the presence of copper, but some of the retorts were composed of gold and silver only in proportions that averaged about 850 and 150, respectively. The ore taken from the Lead King workings is reported to have been somewhat richer than that milled from the Red Cloud. Above adit

No. 4 was a shoot of oxidized ore 250 feet long, said to have yielded $35 a ton and in places near the surface much more.

A large amount of ore is blocked out below the Lead King adit No. 4, and from all that could be learned there is no reason to think that the lower limits of the ore shoots have been reached in either the Lead King or the Red Cloud.

Fourth of July.

The Fourth of July vein crops out along a slope about a quarter of a mile southeast of the Red Cloud mill and from 300 to 400 feet higher. It is developed by four adit levels (Pl. IX, p. 188) to a horizontal distance of 300 feet and a depth of 450 feet on the dip.

The Fourth of July is roughly parallel to the Red Cloud vein and is inclosed by similar rocks. On the northwest and southeast it is cut off by transverse faults that bound a wedge-shaped block pointing southwest. The most probable interpretation of the faulting is that the block has moved relatively southwest and downward. If this is true the Fourth of July vein may be a shifted portion of the Red Cloud, a conclusion supported by the similarity of the two and the fact that the continuation of neither has been found. Both faults dip steeply and are accompanied by abundant gouge and breccia, and the ground between them has been broken by some smaller parallel fractures.

Practically all of the vein so far developed is from 1 to 4 feet in width and is reported to be of about the same richness as the Red Cloud. A small portion only of the vein has been stoped, and the ore produced averaged 1.8 ounces of silver and 1.18 ounces of gold to the ton.

The vein shows a banded structure and is normally composed of quartz and pyrite or its oxidation products. In places there are cavities from which tabular minerals, either ankerite or calcite, have been dissolved.

Robert Emmet.

The Robert Emmet vein crops out about 1,000 feet northeast of the Fourth of July, lies parallel to it, and is within the same fault block. It is opened by adit levels and an incline to a length and depth of 200 feet. The workings were not entered, but they are reported to show a vein similar in general to the Red Cloud. Records of ore shipments made from the Robert Emmet in 1906–7 show a total of $6,000 from ore that averaged 1 ounce of silver and 0.89 ounce of gold to the ton.

Fairview.

The Fairview vein crops out on the steep slope west of Cave Gulch, about three-quarters of a mile southeast of the Red Cloud mine. A tabular ore body from 6 inches to 3 feet wide and 400 feet long was mined from the surface to a depth of 200 feet. Its general direction is east and its dip 30° N., and it is inclosed in schist and quartzite. Records covering the period 1898–1907 show a production of over $50,000. Assays were not seen except for the latest shipments, which averaged 0.77 ounce of silver and 1.1 ounces of gold to the ton. No ore was obtained from the workings in 1916, but specimens in the possession of Dr. Mussigbrod show the ore to be similar in general to that of the Red Cloud. Some of the specimens, however, are unlike any seen in any other mine in the district. In addition to coarse, ragged grains of native gold they contain tellurides of gold, silver, and bismuth inclosed in clear quartz.

Willie.

From a quarry on the east side of First Chance Gulch about 500 feet below the Red Cloud mill a large quantity of ore is said to have been taken that yielded from $4 to $11 a ton in gold. The lode, which is chiefly brecciated and iron-stained schist and quartzite, is known as the Willie lode. To a width of 40 feet or more it is reported to average $2 a ton. An adit level that starts in the bed of a ravine near the quarry penetrates the lode, which has a northwesterly direction, and occupies the core of the anticline previously mentioned as crossing First Chance Gulch below the mill. The folding squeezed and crushed the rocks, opening them for mineralizing solutions which partly replaced them with silica and introduced a little gold-bearing pyrite. Near its face the adit penetrates a vertical northeast fault that is about in line with the second fault met in the Red Cloud adit levels.

COLOMA DISTRICT.

GENERAL FEATURES.

Several mines are grouped closely around Coloma (fig. 22), a mining camp 2 miles northwest of Garnet. During 1897 and the next few years, while the Mammoth and Comet mines were in operation, the camp was lively, but since then it has become almost deserted. In 1916 the only important work in progress was a tunnel being driven by the Montana Gold Mines Co. at a point half a mile north of Coloma and 600 feet lower. Rather extensive development work was formerly done on both the Mammoth and Comet mines, and mills were installed, but from all that could be learned neither mine yielded a profit. Although rich in places, the veins are small, and the work seems to have been planned on a scale out of proportion to them. No records of production were seen, but persons familiar with the mines estimate that more than $200,000 worth of gold ore was extracted from the Mammoth. Some of this ore was shipped to smelters, but most of it is said to have been milled, and all but a little of the gold was lost in the tailings. In the absence of smelter and mill records it is obviously difficult to estimate the production. The Comet is reported to have yielded a few thousand dollars, and the other mines, of which the Clemantha was the most productive, shipped gold ore worth $40,000 or more to smelters.

Coloma is reached by fairly good wagon roads either from Bearmouth by way of Garnet or from Potomac, a town 12 miles to the west on a logging spur of the Chicago, Milwaukee & St. Paul Railway. The mining area lies chiefly upon the summit plateau, which is continuous with and of the same description as that about Garnet. Most of the drainage goes northward through McGinnis Creek, a stream that has yielded much placer gold.

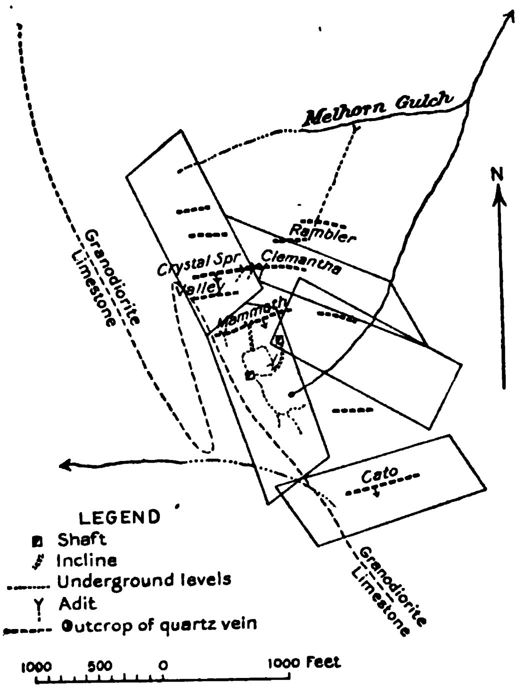


FIGURE 22.—Veins at Coloma, Garnet Range, Mont.

The rocks at Coloma are limestone and granodiorite, both of which are continuous, with simlar bodies exposed at Garnet. The veins occupy fractures in the granodiorite that do not depart far from an east-northeast strike and a 30° S. dip. Most of them crop out very near the contact and within a space of half a mile from north to south. Except locally, they are not more than a foot or two in width, but some of them have been proved by explorations to extend 500 feet or more in length and depth.

None of the old workings were accessible at the time of visit, and information concerning the ore bodies is rather meager. Maps of the Mammoth mine show one stope above the 150-foot level that is 200 feet in stope length and 300 feet on the pitch. Most of this body is said to have been oxidized and rich in gold. There are several smaller stopes, and on the lowest level, which is 270 feet vertically below the surface and also below the limit of oxidation, the general run of the ore is said to be worth from $20 to $30 a ton. Most of the other veins have produced ore near the surface worth $100 a ton, but none except the Comet are developed below the oxidized zone. Little was learned about the Comet beyond the fact that exploration has shown the vein to be generally very lean below a depth of 100 feet or less.

Specimens of sulphide ore from the Mammoth and Comet veins are rather similar in structure and mineralogy to the ores from the veins in the granodiorite at Garnet. Banding due to a replacement of the wall rock is common, and pyrite, chalcopyrite, and tetrahedrite, together with quartz, compose the ore. Tetrahedrite is notably abundant in the Comet ore, and in this mine and the Mammoth also it cuts and replaces the other sulphides. Specimens from the lower levels of the Comet show considerable white mica, and the quartz is rather coarse textured, suggesting a pegmatite. The oxidized ore consists, as usual, of porous quartz and iron oxides in earthy masses and as pseudomorphs after pyrite.

The texture and comparative poverty of the Comet vein, together with the fact that its outcrop is 700 feet lower than the Mammoth and also that much deeper in the granodiorite body, other things being equal, suggest that it may lie near the lower limit of the zone in which the gold-bearing pyrite was deposited. This being true, the depth of 700 feet in the Mammoth, or corresponding levels in other mines, may be a lower limit for good ore, the whole area being so small that the conditions surrounding the formation of all the veins were probably much the same. The tetrahedrite is of a later generation and apparently wholly independent of the gold-bearing pyrite and is probably not subject to the above limitations. In fact, there is nothing to indicate that this copper mineral does not persist in the veins to considerable depths, or even increase downward. In view of these considerations the completion of the tunnel now being driven by the Montana Gold Mines Co. to intersect the Mammoth vein at a depth of approximately 600 feet is awaited with interest.

MINES AND PROSPECTS.

MONTANA GOLD MINES CO.

From a point in Melhorn Gulch about 5,350 feet above the sea a tunnel is being driven southwestward to crosscut the Mammoth and other veins that crop out at Coloma. In September, 1916, about 1,000 feet of large, straight, and well-constructed tunnel had been completed under the supervision of Andrew Ryan, and about an equal distance remained to be run before a point directly beneath the shaft house on the Mammoth and about 600 feet below the surface would be reached. The tunnel penetrates granodiorite and has crosscut a few small easterly quartz veins or stringers that dip 30°–40° S. Some of them show a little pyrite, and some are crushed by postmineral faulting in the plane of the vein. Generally the country rock is solid, but here and there it is slightly crushed and faulted.

The Mammoth vein is developed by a shaft reported to be 270 feet deep and several levels and stopes, none of which could be entered in September, 1916. The shaft and hoist were in an advanced stage of dilapidation and evidently had not been in use for several years. From 1896 to 1899 the mine was developed on a rather ambitious scale, and a mill was built in Washoe Gulch, about a mile to the west. Ore worth $200,000 or more in gold is said to have been mined and worked in the mill. No records of ore production or mill runs were seen, but the mill extraction is said to have been unsatisfactory, most of the gold having remained in the tailings.

The vein strikes about east and dips 30° S., and a large part of it is said to be from 1 to 3 feet or more in width. It cuts granodiorite adjacent to limestone, but does not cross the contact. Another similar vein follows the contact, which strikes southeast and dips steeply east. In the upper levels the ore in both veins was oxidized and reported to have been of high grade. Sulphide ore at a depth of 270 feet is said to average from $20 to $30 a ton in gold. The few specimens seen are similar in appearance to ore from Garnet, showing pyrite and tetrahedrite in a quartz gangue. The tetrahedrite was, as usual, the last mineral to be introduced into the vein.

Several veins parallel to the Mammoth crop out within a quarter of a mile north and south from it. Their value will doubtless be determined by the crosscut tunnel now being constructed. Named in order, those on the north, which have been the most extensively worked, are the Valley, Crystal Spring, Clemantha, and Rambler. None of these could be seen underground in September, 1916, but they are described by persons familiar with them as narrow veins similar in character to the Mammoth and are reported to have produced rich oxidized ore from their rather superficial workings. The Clemantha is said to have yielded $30,000, and the others smaller amounts.

South of the Mammoth is the Cato, which is one of the first of the veins to be exploited in this locality and for which a small production is reported.

COMET (OLYMPIAD).

The Comet mine, now partly included within the Olympiad claim of B. W. Champe, is three-quarters of a mile north of Coloma, near the head of Bivins Gulch, a tributary of Elk Creek. About 1905 a corporation known as the Quantock Mining & Milling Co. spent a large sum in development work and installed a 15-ton Huntington mill. But a very small production of gold is said to have been made, however, and the company has to all appearances abandoned the ground.

A two-compartment shaft, with its collar about 5,250 feet above the sea, is said to have been sunk 500 feet on the vein, and several levels were run, one of them a crosscut 1,000 feet to the south. In September, 1916, the shaft was caved within a few feet of the collar. The vein is narrow, strikes N. 60° E., dips 30° S., and cuts granodiorite. Near the surface there were a few bunches of oxidized ore worth $100 a ton in gold. Below this a few small shoots of sulphide ore were found, specimens of which are fairly rich in tetrahedrite. The other sulphides present are pyrite and chalcopyrite, named in the order of their genesis, and both of them are replaced by the tetrahedrite. The gangue is quartz, which ordinarily forms 90 per cent or more of the vein. The long crosscut is understood to have been run in an unsuccessful search for a vein that crops out a short distance south of the Comet. Specimens from the lower workings show considerable white mica, and the quartz is rather coarse textured, features that suggest pegmatite.

HEAD OF ELK CREEK.

GENERAL FEATURES.

Several mines are located along the main divide and the adjacent slopes near the head of Elk Creek and about 2 miles east-southeast of Garnet (fig. 23). Since 1886, when the first one was opened, they have been worked now and then, producing in the aggregate $40,000 to $50,000 in gold. The district is reached from Garnet by an excellent road around the south of Anderson Hill, and, in addition, a road goes from the pass at the head of Elk Creek down Deep Gulch to the highway between Garnet and Bearmouth.

Most of the area drains northward to Elk Creek, chiefly through Day Gulch, a stream that has yielded much placer gold, but a small part is drained by Cayuse Gulch, a tributary of Deep Creek. The area is thickly timbered and abundantly supplied with water.

The surface is similar to that at Garnet. The main divide is an undulating flat that averages a little more than 6,000 feet in elevation and has been deeply scalloped along the borders by gulches from either side. Stones Flat, now a part of the divide, is the remnant of an ancient valley through which a good-sized stream once flowed and deposited placer gravels. The broad pass at the head of Elk Creek is a remnant of another old valley. A short distance away from the divide the surface becomes rugged and steeply sloping.

Beds of quartzite, shale, and schist continuous with those at Garnet occupy most of the surface. They likewise pass beneath limestone and are invaded by granodiorite, of which the principal exposure occupies the basin of Day Gulch. In general the beds are bent into a broad arch, which is a continuation of the one developed at Garnet. Locally, however, there are many variations in the strike and dip, the mine workings commonly disclose faults, and the structure is evidently complex in detail.

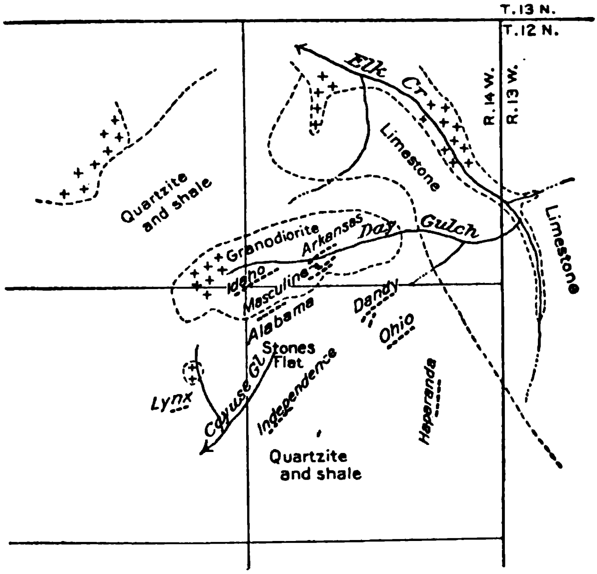


FIGURE 23.—Veins at the head of Elk Creek, Garnet Range, Mont.

LODES.

The lodes at the head of Elk Creek may be all classified as quartz-pyrite veins valuable for gold. They have been formed along fractures that cut the sedimentary rocks and the granodiorite, and, except the Haparanda, which trends north, they have a northeast direction. Most of them dip steeply northwest and all are fairly persistent though narrow. The most extensively developed of these veins, the Dandy, is shown to extend 1,000 feet or more along the strike and 500 feet on the dip without any indications that its lower limit is near. It varies in width but averages 2 feet for considerable distances.

Most of the other veins are narrow, and few of them have been explored more than 100 feet in depth or 200 feet in length. In most of the mines faults have been met that cut off the veins abruptly, but the amount of dislocation is known only for one or two of them. A fault that cuts the Dandy vein, between adits Nos. 1 and 2, has dropped one part relatively about 150 feet, measured on the fault plane, resulting in a horizontal shift of the vein at any given level of about 200 feet. Most of the other faults carry as abundant gouge and breccia as this one, and their dislocations may well have been equally great.

The lower limit of oxidation has been reached in only one or two mines, in which it is about 200 feet below the surface. Unoxidized pyrite is found at less depths, but as a rule only where the vein is tight and admits little water.

In the veins which have so far proved to be the most profitable, and of which the Dandy is an example, the pyrite or the iron oxides derived from it are more or less concentrated in a middle streak that contains most of the gold. As a rule, however, this streak can not be separated in mining from the leaner quartz on either side, and the whole must be taken out and averaged together. In the other veins most of the pyrite occurs in small veinlets irregularly distributed through the quartz. Ore shoots, or portions of the veins that average sufficiently rich to repay working, range from a few to perhaps several hundred feet in length and depth. A fact that seems well established is the limitation of rich ore—that is, ore worth about $100 a ton—in most of the veins to depths within 50 feet or so of the surface. Except in spots the ore is leaner below, although still in the oxidized zone, and the sulphide ore farther down is of still lower grade. The decrease in tenor experienced in crossing the lower boundary of the oxidized zone, which in the Dandy amounts to the difference between ore worth $30 a ton and ore worth $20 a ton, is explained by the loss of valueless material in the course of oxidation and leaching, but the localization of richer ore just below the surface is not so easily accounted for. There is no evidence of downward enrichment in the sulphide zone.

The close association of these veins with intrusive granodiorite strongly suggests that they are a consequence of the intrusion of that rock, their minerals being formed from solutions given off when the magma cooled. Most of the veins are too small to warrant plans for very deep exploration, although there is no reason to think that the depth limit of ore has been reached.

MINES AND PROSPECTS.

DANDY.

The Dandy mine, on the slope west of Elk Creek about 2 miles east-southeast of Garnet, has been operated in recent years by the Ohio Mining & Development Co. There is a newly constructed building on the property equipped with a Lane mill, amalgamating plates, and concentrators, but it was idle in September, 1916, and the results of previous runs were not learned. A moderate-sized stope above adit

No. 2, the yield of which is not known, and a smaller stope in adit No. 1 that produced $13,000 in gold, are reported to have been made by predecessors of the present company.

Three adit levels have been driven southwest, wholly or in part following a vein in the Dandy claim. The lowest adit, No. 3, is 1,000 feet long and lies about 5,800 feet above the sea. Levels 2 and 1 are about 175 and 350 feet higher, respectively, and 850 and 200 feet in length. At their farther ends levels 3 and 2 are about 400 feet deep in the vein. In addition there are several crosscuts and raises, and altogether about 3,000 feet of underground work has been done.

The formation consists of slaty mica schist and quartzite similar to many of the beds at Garnet, and in addition there is considerable very dark shale. A short distance to the east these rocks are overlain by limestone, and to the north they give place to granodiorite. A granodiorite dike is also met in adit No. 3 about 300 feet from its mouth. In general the sedimentary rocks strike northwest and dip at moderate angles northeast, but they show many local variations in attitude and the structure is complex in detail.

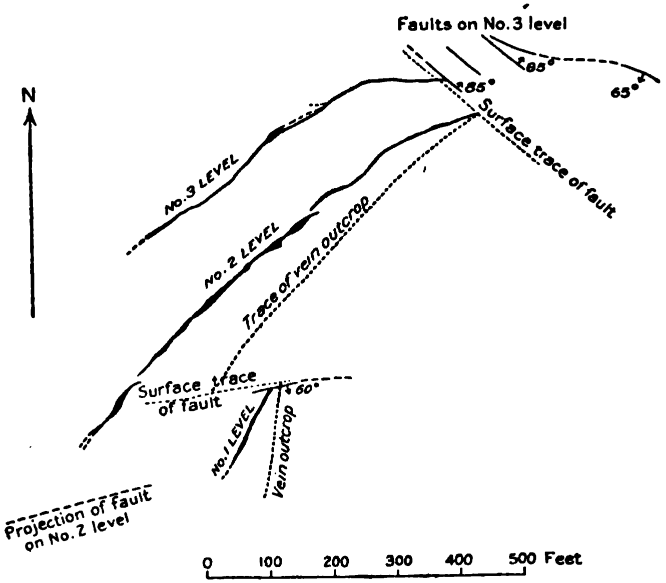


FIGURE 24.—Plan of Dandy vein, Garnet Range, Mont.

The vein dips 55°–75° NW. and cuts the quartzite, schist, and shale at right angles to their general direction. It is exposed by adits Nos. 2 and 3 to a length of nearly 1,000 feet, in which its continuity is practically unbroken, although there are two or three small interruptions where the vein leaves one plane for another parallel fracture a few feet away. There are some extensive pinches (fig. 24), but over most of the course described the vein averages at least 2 feet in width and in places reaches 3 or 4 feet.

A fault that strikes nearly east and dips 60° south has shifted that portion of the vein exposed in adit No. 1 about 200 feet to the south. The vein is again cut off near the mouth of adit No. 2 and at a point below in adit No. 3 by a northwesterly fault zone, the planes of which are vertical or dip very steeply northeast. Farther east there is a fault that strikes a little north of west and dips southwest. The vein itself lies in a fault fissure and has been slightly crushed by postmineral movement.

Generally the vein shows a banded structure, in places containing thin partings and horses of country rock, and is composed wholly of quartz and pyrite or the oxidation products of pyrite. As a rule most of the pyrite is gathered along the middle of the vein, forming a streak locally as much as a foot thick. In the oxidized ore the pyrite streak is represented by a porous or "honeycomb" quartz partly filled with limonite. Most of the quartz is rather fine grained, milk-white, and dense, but in places there is a coarser transparent variety that, together with some of the pyrite, seems to be of a later generation.

Oxidation is practically complete above and for short distances below level No. 2, its lower limit lying about 150 to 250 feet below the surface and sloping in the same direction.

Adits Nos. 2 and 3 are unconnected, but there are some raises and small stopes that extend part way between them and afford means for a tolerably comprehensive sampling of the vein. As indicated by the results obtained by several engineers, all of whom estimate a large tonnage in sight, considerable portions of the vein above No. 2 appear to average about $30 a ton in gold, and the corresponding sulphide ore on No. 3 level about $20 a ton. The assay plats suggest that there are two or more persistent ore shoots that pitch slightly westward in the plane of the vein, and in addition some rich spots between.

OHIO AND BUCKEYE.

About 800 feet south of the Dandy a vein has been opened on the Ohio and Buckeye claims. This vein strikes southwest, stands vertical, ranges from 2 to 5 feet in width, and is composed of dense white quartz. Here and there it contains specks of pyrite, and samples from it are said to have assayed $2 or $3 a ton in gold.

HAPARANDA.

The Haparanda mine is on the slope west of Elk Creek about half a mile southeast of the Dandy. It was opened in 1886 by B. A. C. Stone, who built a small mill and extracted about $10,000 in gold.

The property has lain idle many years, and the workings are caved. Mr. Stone describes the vein as having a nearly due north trend and a dip of 85° E. Near the surface there was a rich ore shoot 2 feet thick and 30 feet in stope length that pitched 20°–30° N., parallel to the mountain slope. Beyond this shoot the vein was explored for some distance but proved to be lean. The formation is quartzite and schist, and the vein minerals are quartz and pyrite or iron oxides derived from it.

MASCULINE AND ARKANSAW.

The Masculine and Arkansaw mines, neither of which was being worked in 1916, are in Day Gulch a quarter of a mile northwest of the Dandy. Both veins strike N. 65° E., dip 75°–80° NW., and cut granodiorite. The Masculine, which is from 1 to 2 feet wide, is developed by a short tunnel and a shaft said to be 175 feet deep. At the bottom of the shaft the vein is cut off by a fault that dips north. Ore scattered about the dump is a fine-grained flinty quartz that contains abundant fine pyrite in secondary fractures. Near the surface the ore contains a large amount of iron oxides and is said to assay from $20 to $40 a ton in gold.

The Arkansaw is a foot or less in width and of similar composition to the Masculine. It is said to be developed to a depth of 65 feet and to assay from $40 to $80 a ton.

IDAHO AND ALABAMA.

The Idaho and Alabama mines are in the upper part of Day Gulch, just north of Stones Flat. The veins in both strike northeast, dip 25°–30° SE., and are a foot or less in width. The Idaho vein is in granodiorite and has been developed by an adit level several hundred feet long. From an ore shoot 50 feet long, it is said, about 100 tons of ore that averaged $100 a ton in gold was shipped by way of Bearmouth to smelters. The vein minerals are quartz and pyrite or its oxidation products.

The Alabama vein is in schist, very near the granodiorite contact, but has not been extensively developed. It is similar mineralogically to the Idaho.

INDEPENDENCE.

The Independence is a prospect on the slope east of Cayuse Gulch and near the Elk watershed, developed by an adit level at an elevation of 5,950 feet above the sea, driven northeastward 150 feet. For the last 30 feet the adit follows a N. 55° E. vein that dips 75° NW., ranges from 1 foot to 4 feet in width, and is composed of a dense milk-white, rather flinty quartz, through which fine-grained pyrite or iron oxides derived from it are distributed along a network of small cracks.

LYNX.

The Lynx mine is about a quarter of a mile southwest of Stones Flat, in a ravine tributary to Cayuse Gulch. An adit level 240 feet long follows in part a S. 80° W. vein that dips 75° S. and cuts quartzite. At 165 feet from the portal the vein is cut off by a N. 25° W. fault which dips 85° W., and along which there is a short drift to the north. The fault movement has apparently been normal, and has probably shifted the vein a considerable distance to the north. Beyond the fault the adit continues into a zone of broken and disturbed rocks.

The vein ranges from 1 foot to 3 feet in width and is composed of quartz and iron oxides derived most probably from pyrite. As a rule the iron oxides, which constitute the valuable portion, form a streak in the middle of the vein that ranges from a few inches to a foot or two in width. At 80 feet from the portal a stope 30 feet long begins that extends nearly to the surface and is said to have yielded a moderate quantity of ore worth about $80 a ton in gold.

A short distance north of the Lynx tunnel a small working exposes 25 feet of soft material that is rich in earthy iron oxides and is said to contain fragments of copper ore. This deposit adjoins a small body of intrusive granodiorite and has the appearance of decomposed garnet rock like that of the contact-metamorphic deposits at Top o' Deep.

TOP O' DEEP DISTRICT.

HISTORY AND PRODUCTION.

In the basin at the head of Deep Creek small gold-bearing quartz veins were uncovered by placer mining as early as 1866. At different times since then some of them have been mined to shallow depths, and work was done also on the copper-bearing contact-metamorphic bodies in the hills around the basin. In the summer of 1916 only one mine—the Mountain—was being worked. Most of the claims in the district are patented, and the idleness of some of them is said to be caused by litigation. Altogether the lodes have yielded about $50,000, of which much the greater part was in gold and the remainder in copper.

GEOGRAPHY AND GEOLOGY.

Deep Creek heads in a small basin about 6,000 feet above the sea. Slopes that border it on the east, north, and west rise gently 500 feet or more to a rather broad, undulating divide, beyond which the drainage goes to Weasel Gulch on one side and Elk Creek on the other. The summit north of the basin has an average elevation of

6,650 feet, and one point to the east reaches 6,826 feet. A short distance away from the divide the streams descend into deep, narrow valleys, and the surface in general becomes steep and rugged.

The Deep Creek basin is almost wholly occupied by an intrusive body of granodiorite that has come up through limestone. The exposed portion of this body has a roughly circular form, is about a mile across, and extends northward over the divide into Weasel Gulch. Field evidence shows the exposure to be the top of a mass that expands in depth and is probably connected beneath the surface with the main granitic body exposed at Garnet. There is reason to believe that before it was uncovered by erosion the granodiorite mass projected but little higher than the present rim of the basin. Deep Creek has cut down into it 700 feet or more.

As a rule, to a distance of several hundred feet from the contact the limestone is changed to a white marble, and portions on the top and upper slopes of the intrusive body are replaced by a rock composed of garnet, magnetite, and other contact-metamorphic minerals. North and east of the Deep Creek basin is an area of andesite lava, a formation not known to contain valuable mineral deposits in this region.

LODES.

CLASSIFICATION.

The lodes in the Top o' Deep district form two groups that are distinct in age, origin, and character. The older deposits, of which the Mountain is an example, are masses of garnet and other metamorphic substances that contain copper minerals and occur in limestone next to the intrusive granodiorite. Quartz veins formed by replacement along fractures that cut the granite and the metamorphic bodies also form a later group, chiefly valuable for gold.

CONTACT-METAMORPHIC DEPOSITS.

General character.—The metamorphic bodies are most abundant in high situations and rather significantly absent along Deep Creek and Weasel Gulch at the lowest exposed portions of the contact. From the Red Rock mine they extend northward about a mile, and they also form a shorter chain along the west side of the granodiorite at the Mountain mine.

In detail the metamorphic bodies are irregular, but as a rule their greatest dimensions are parallel with the contact. The body on which the Boston mine is located is bent in the form of a crescent and is almost completely surrounded by the granodiorite. It is 3,000 feet or more in length and about 500 feet in extreme width, and the rather meager information afforded by underground workings shows it to taper downward like a blunt wedge. The body at the Pearl mine is from 10 to 50 feet wide and at least 300 feet deep. Its length is not shown, but it doubtless extends with some breaks as far south as the Red Rock, a distance of half a mile. Although very irregular in detail, the boundaries of these metamorphic bodies appear to be generally sharp and distinct. No gradual change from the rock that is chiefly garnet and magnetite to granodiorite on one hand or limestone on the other was observed. A flinty quartz that is commonly red or brown with iron oxides forms bodies closely associated with the metamorphic mass and rather indefinitely separated from the limestone. In places the metamorphic bodies faintly show a banded structure caused by a partial segregation of the minerals in layers.

Ore shoots.—Copper minerals appear to be rather generally but sparingly distributed through the metamorphic bodies. An average sample from a pit on an outcrop in the Red Rock claim is reported to have assayed 1.5 per cent copper, and a 2-foot streak in the Mountain mine is reported to contain from 5 to 8 per cent copper. The streak in the Mountain mine, however, is not sharply separated from the leaner portions of the mass, and not enough work has been done to show its limits.

The gold-copper ore shoots worked in the Pearl mine, although inclosed in a metamorphic body, belong mainly to a later quartz vein and are described in succeeding pages.

Mineralogy.—In the following list the minerals of the metamorphic deposits are classified as primary and secondary, according to whether they were deposited originally in the lodes or were formed later:

PRIMARY MINERALS.

Pyrite	Sparingly disseminated grains inclosed by garnet and magnetite.
Chalcopyrite	Irregularly distributed grains intergrown with garnet and magnetite.
Quartz	Locally abundant and flinty, replacing limestone.
Magnetite	Next to garnet the most abundant mineral of the deposits. For the most part it has a rather fine granular texture, but in places it forms good-sized tabular crystals.
Calcite	Absent from the lodes generally but occurs in places as rather large crystals inclosing green hornblende and other minerals. The marbleized limestone is made up chiefly of rather coarse calcite grains.
Garnet	Forms the bulk of the deposits and is chiefly the brown lime-iron variety, andradite. Occurs in compact granular masses but also shows well-developed crystal faces, some of which are an inch across.

Epidote	Abundant and generally fine grained. Occurs throughout the deposits, and also in parts of the adjacent limestone.
Actinolite (green hornblende)	Observed in one place only where it is intergrown with epidote. Occurs in parts of the adjacent limestone.
Tremolite (white hornblende)	Locally abundant as radial aggregates in limestone near the contact.

SECONDARY MINERALS.

Native gold	In cavities in boulders of metamorphic rocks found in Bilk Gulch. Adheres lightly to the faces of garnet crystals and is associated with chrysocolla. Is thought to have been introduced into the metamorphic body by the later quartz veins and to have migrated when the veins were oxidized.
Chalcocite	Fills small cracks in chalcopyrite from the Pearl mine. Apparently produced by downward enrichment.
Chalcedony	Lines small cavities and is abundant in the limestone adjacent to the metamorphic bodies.
Iron oxides	Abundant in the weathered portions of the lodes. Produced by the decomposition of magnetite and iron-bearing silicates and sulphides.
Copper oxides	A black oxide (tenorite?) stains specimens from the Pearl mine.
Malachite	Forms thin coatings and crusts in the upper portion of the lodes. Observed in places to be forming from chrysocolla.
Chrysocolla	Valuable as an ore mineral. Fills seams and small cavities in the upper portions of the lodes. Produced by the weathering of chalcopyrite and the accompanying silicate minerals.

Alteration and genesis.—Some of the metamorphic bodies are considerably decomposed at the surface, the garnet and other silicates having broken down to an ocherous clayey mass and even the magnetite appearing to have changed to limonite. These changes, however, do not extend downward more than a few feet. Most of the metamorphic bodies show rather fresh garnet and other silicates as well as magnetite at the surface. As a rule, oxidation of the copper-bearing sulphides is well in advance of any extensive disintegration of the other minerals but appears to be accompanied by a partial destruction of the garnet. Chrysocolla appears everywhere to be the chief oxidation product and to have migrated from its places of origin to the crystal-lined vugs or other cavities that are numerous in the deposits. Locally native gold is so intimately associated with chrysocolla that the two appear to have been carried by the same solution. At the surface the chrysocolla appears to be unstable, for it is commonly observed passing directly into malachite. In places the chrysocolla has been carried down below the unoxidized chalcopyrite. At a depth of 40 feet in the Mountain mine the two minerals overlap, forming an enriched zone, the extent of which, however, is not known. Doubtless similar zones have been formed in the other lodes.

A significant fact concerning the metamorphic bodies is their grouping around the higher portions of the granodiorite body. The Boston, Hartford, and others of the largest outcrops are at the very summit of the intrusive mass, and the Mountain, Pearl, and the remaining deposits of any considerable size are very near the top. At low situations, however, as where Deep Creek and Weasel Gulch leave the granodiorite area, hardly a trace of a metamorphic body such as the deposits under consideration is to be seen.

The metamorphic bodies were evidently derived from the granodiorite by heated vapors that carried large quantities of iron and silica and a little copper into the limestone. The pressure being less at the top of the intrusive mass than elsewhere, the vapors with their mineral burden escaped there the most freely.

Conclusions.—Although it appears that none of these lodes are more than a few hundred feet deep, many are extensive enough in other directions to be of value if any considerable portions of them are of workable grade. As the distribution of the copper minerals is irregular, the exploration of these lodes has to be carried on more or less blindly, but the most probable situations for ore are the zone in which the chalcopyrite and chrysocolla overlap and the limestone side of the metamorphic body. Wherever present this enriched zone is probably within 50 feet of the surface. In several other mining districts ore is found most abundantly on the limestone side of garnetiferous deposits, although, so far as the writer is aware, no adequate explanation of this has been advanced. Development work is not extensive enough to determine whether or not this rule applies at Top o' Deep, but nevertheless it is thought advisable to explore the limestone side carefully.

Concentration of this ore would be difficult because of the heaviness of the gangue minerals, but the large percentage of iron may be generally counted upon to procure favorable smelter rates.

QUARTZ VEINS.

Many small quartz veins cut the granodiorite body at the head of Deep Creek and occur also in the metamorphic rocks on the divide between that stream and Bilk Gulch. Most of them are but an inch or two wide, and they show a variety of strikes and dips. A few attain widths of a foot or more and contain small but rich bodies of gold ore. In part the quartz has replaced the wall rock along fractures or shear zones, and in part it has filled open spaces, as is shown by the growth of free crystals outward from the walls.

Ore bodies from a few inches to a foot or more in thickness and 30 to 40 feet in length and depth have been worked in the upper portions of these veins, most of which have not been explored more than 40 or 50 feet below the surface. In the Pearl several small irregular ore shoots occur between the surface and a depth of 200 feet, the largest one above the 100-foot level. On the Red Rock and Gold Leaf ore extended from the surface down about 40 feet.

Oxidation is complete at least 40 or 50 feet below the surface at the Red Rock and to a somewhat less depth at the Pearl.

The mineralogy of the veins is simple. Grains and small masses of pyrite and chalcopyrite, both presumably gold bearing, together with small amounts of native gold, were introduced with the quartz. In the oxidized ore limonite has replaced the sulphides and commonly retains the crystal form of pyrite. Particles of native gold are embedded in the limonite but in some specimens are inclosed in quartz without any accompanying iron minerals. Chalcopyrite is rather abundant in the Pearl and the other veins that cut metamorphic rocks but apparently is not plentiful in the veins in granodiorite, as suggested by the scarcity of copper stains in these veins. A little enrichment by chalcocite, copper oxides, and chrysocolla has occurred in the Pearl. It may have been caused, however, by the oxidation of copper minerals introduced with the metamorphic deposit as well as from the later quartz vein.

Though smaller and differing somewhat in mineralogy, the quartz veins are similar in general character to those associated with granodiorite near the town of Garnet. They are thought to be of essentially the same age and likewise an effect of the intrusive magma. Because of their small size these veins do not encourage deep exploration, although they are doubtless rich to considerable depths. Their importance collectively as a source of placer gold is shown by the extensive and rich gravels in the gulches below.

MINES AND PROSPECTS.

MOUNTAIN.

The Mountain mine, operated in 1916 by H. P. Hanifin, is on the western rim of the basin at the head of Deep Creek, at an elevation of 6,400 feet. The production by former operators of a carload of ore that yielded 16 per cent of copper but little or no gold and silver is reported, and ore for shipment was being taken out by Mr. Hanifin in September, 1916.

A shaft sunk at the contact between intrusive granodiorite and limestone penetrates a mass composed mainly of garnet, magnetite, and epidote. At a depth of 40 feet drifts aggregating 50 feet in length extend north and south from the shaft and show the metamorphic body, which may be regarded as the lode, to be at least 10 feet wide. A few workings along the outcrop indicate the probable length of the lode to be several hundred feet.

The most abundant ore minerals are chalcopyrite and chrysocolla. Malachite, mainly derived from the alteration of chrysocolla, forms coatings in cracks and seams but is not abundant. Chrysocolla fills seams and cavities, some of which are the size of a hickory nut, and is widely but irregularly distributed through the lode. At the depth of 40 feet most of the chrysocolla is fresh, compact, and of a fine turquoise-blue color—qualities that may give it some value as a gem stone. The chrysocolla is clearly of later origin than the chalcopyrite and the silicates composing the gangue, and was probably derived from the weathering of those minerals. Grains of chalcopyrite appear here and there at the 40-foot level and are more abundant than elsewhere in an irregular ill-defined streak about 2 feet wide that is not far from the limestone. Samples of this portion of the lode are said to assay from 5 to 8 per cent of copper. The chalcopyrite is intergrown with the garnet and magnetite and apparently came into the lode with them. Pyrite occurs also as a primary mineral intergrown with magnetite.

The brown lime-iron variety of garnet known as andradite forms the bulk of the lode. Most of it is coarsely granular and massive, but well-formed crystal faces are shown in the numerous small cavities in the rock. The magnetite and epidote are finer grained, and the three are partly intergrown and partly segregated in rather indistinct bands. Locally a little quartz is associated with them.

PEARL.

The Pearl mine, on the divide between Deep Creek and Bilk Gulch, is reported to have produced about $20,000 worth of gold-copper ore. It is developed by a vertical shaft 300 feet deep from which levels have been run at depths of 100, 150, 200, and 300 feet. No work was being done in August, 1916, and the mine evidently had been idle for several years.

Open pits expose a deposit of garnet-magnetite-epidote rock, at the contact of granodiorite and limestone. The garnet is the brown lime-iron variety andradite and is rather coarse grained. The epidote and magnetite are finer, and the three are intimately intergrown in some places and partly segregated in others. Here and there the rock contains a little quartz sand. Chrysocolla and malachite fill cracks, seams, and small cavities, and a few grains of unoxidized chalcopyrite remain. Irregular bodies of flinty quartz, clouded with iron oxides, occur here and there in the limestone next to the metamorphic body. The underground workings were not entered by the writer, but from a miner familiar with them the following facts were learned: The contact plane is very irregular and has an average nearly vertical dip under the limestone. The metamorphic body ranges from 10 to 50 feet in thickness. At the 100-foot level a steeply inclined ore shoot from 2 to 10 inches thick and 20 feet long was stoped to a height of 40 feet, yielding about $15,000, chiefly in gold. The 150-foot level cut a narrow vertical pipe of ore, worth from $20 to $200 a ton in gold and copper, and a little below 200 feet the shaft went through a small flat-lying shoot of good ore. All the ore bodies are in the garnet, but at no regular distance from either the granite or the limestone. A level at the bottom of the shaft (300 feet) explored the granite but found no ore of consequence.

Specimens of ore said to have come from the shoots mentioned are portions of small quartz veins cutting the garnet rock. Two kinds of quartz occur—a coarsely crystalline kind that incloses sulphides and a compact flinty kind that contains chrysocolla, malachite, and copper oxides. The flinty quartz is the later of the two and is doubtless secondary, but the more coarsely crystalline quartz resembles that of the gold-bearing veinlets in the granodiorite. It incloses grains of pyrite and chalcopyrite, and in one specimen fine particles of gold were observed adhering to a partly oxidized grain of chalcopyrite. In addition chalcocite fills small cracks and seams in the ore. The Pearl lode is evidently a metamorphic deposit similar to the Mountain, but in addition it is cut by some later gold-bearing quartz veinlets. A little enrichment in copper and possibly also in gold has occurred. In Bilk Gulch below the Pearl float boulders, described on page 237, in which gold and chrysocolla are found together in cavities, indicate that a secondary transfer of the gold has taken place in the lode from which these boulders came.

BOSTON, HARTFORD, AND GOLDEN ANGEL (KLONDIKE).

A short distance northwest of the Pearl mine, on the hill at the head of Deep Creek, is an outcrop of garnet-magnetite-epidote rock shaped like a crescent open to the west. This body is about 3,000 feet long and 500 feet across at its widest part, and except on the east, where a neck joins it to the limestone, it is entirely surrounded by granite. Prospect pits here and there show copper-stained rock similar to that at the Pearl and Mountain mines. No work was being done on this deposit in August, 1916, and no ore shipments are reported. Some open pits and a shaft on the Boston claim are along the middle part of the crescentic mass. Here a copper-stained outcrop 50 feet across stands rather prominently above the general surface. As shown by the natural exposures, the open pits, and the shaft dump the body is composed mainly of rather coarse-textured brown garnet (andradite), magnetite, and epidote, named in their relative order of abundance. The garnet and magnetite are intimately intergrown, and the epidote appears generally to fill interstitial spaces. Cavities are lined with well-formed garnet crystals covered with crusts of chrysocolla, which in the more weathered specimens may be seen with the aid of a hand lens altering directly into malachite.

Here and there the mass is cut by irregular quartz veins an inch or two in width that contain a little pyrite and chalcopyrite. In addition a flinty red and brown quartz locally replaces the garnet rock. Oxidized portions of these veinlets are coated with chrysocolla and malachite, and some specimens contain small particles of native gold. In addition the metamorphic rock is commonly copper stained, though no unoxidized chalcopyrite was seen in it. The shaft is said to be 100 feet deep and to have ended in granite.

On the Hartford and Golden Angel claims, on the northern and southern horns of the crescent, respectively, the workings show the results of mineralization similar to that at the Boston. At the Golden Angel green hornblende (actinolite) occurs in addition to the other metamorphic minerals, and the contact plane, as shown by a shaft 100 feet deep, is said to dip steeply under the metamorphic body.

No assays showing the amounts of copper and gold in any of these deposits are available, but some of the rock looks rich enough to justify careful sampling.

RED ROCK.

The most extensively developed quartz vein in this district is the Red Rock, near the eastern edge of the granodiorite, about a quarter of a mile above the old mining camp of Top o' Deep. Ore from the Red Rock worked in an arrastre is said to have yielded between $10,000 and $12,000 in gold. The workings consist of open cuts, tunnels, and drifts, most of which are caved and which explored the vein along the outcrop for 500 feet or more. The vein has a nearly flat dip and is about a foot in average width, and its quartz is not unlike that of the Cascade vein, near Garnet. Limonite is abundant as earthy masses, stains, and scattered grains, some of which still preserve the crystal form (cube) of the pyrite from which they were derived. In specimens broken from the vein small particles of gold were seen embedded in the limonite, particularly in the cubelike grains. The gold is said to be more or less concentrated in spots or pockets, some of which were very rich. The wall rock is largely altered to a felty mass of very fine mica (sericite), and is deeply stained with oxides of iron.

Along the contact near the center of the Red Rock claim pits show 6 feet or more of soft earthy limonite that is plainly decomposed garnet-magnetite rock. Farther north along the contact other pits expose a copper-stained body of garnet rock and silicified limestone that is said to assay 1.5 per cent of copper.

Much of the silicified limestone resembles vein quartz to the unaided eye, and has been excavated in the expectation of finding gold but without success. Under the microscope it is seen to be composed of very fine grained quartz and opal, thickly clouded in places with iron oxides. It is much finer textured than the gold-bearing vein quartz, and was apparently formed by replacement of the limestone when the garnet rock was introduced.

GOLD LEAF.

The Gold Leaf mine is in granodiorite about a quarter of a mile north of the Red Rock or half a mile north of Top o' Deep. Several open cuts and an incline said to be 40 feet deep are made on a quartz vein that ranges from a few inches to a foot in width and is similar in composition and texture to the Red Rock vein. "Cubes" and irregular masses of limonite containing fine particles of free gold occur in it, and some of them show unoxidized kernels of pyrite and, rarely, of chalcopyrite. An open cut 100 feet long made on the outcrop is said to have yielded $7,000 from ore worked in an arrastre. The wall rock is extensively sheared, altered, and rusty, and is said to assay $2 or $3 a ton in gold.

COPPER CLIFF DISTRICT.

HISTORY AND PRODUCTION.

A small but very interesting district known by the name of its principal mine, the Copper Cliff, lies along the main divide about 6 miles in an air line west-southwest of Garnet. It is reached from Bonita station on the Northern Pacific and Chicago, Milwaukee & St. Paul railways by a good road, 10 miles long, up Cramer Creek. There are also less-traveled roads to Copper Cliff from Bearmouth, another station on the railways mentioned, and from Potomac, a town on the main highway, up the Blackfoot Valley.

Since the discovery of the Copper Cliff lode in 1891, which caused a mild excitement at the time, mining has been rather spasmodic. The total production is about 150,000 pounds of copper and very small amounts of gold and silver.

GEOGRAPHY.

The general surface features at Copper Cliff are similar to those at Garnet, Coloma, and other places along the summit of the Garnet Range. The main divide and its most prominent spurs are remnants of an ancient flat or gently hilly surface into which the streams have cut deep gulches from either side. The general summit level at Copper Cliff, however, is about 5,500 feet, or 500 to 1,000 feet lower than is usual in the Garnet Range—a difference that is significant of warping or other structural deformation of the ancient surface. The mining area lies just north of the watershed, extending from the summit level down a short gulch that empties into Union Creek not far below its head. Below the Copper Cliff the gulch is steep, narrow, and straight, having a course of N. 50° E., but the small portion above the mine is crooked, flat, and open toward the head. The noticeable feature of this gulch is the Cliff, a huge upright slab of rock at the foot of the slope on the left and about a third of the way downstream from the head. From a viewpoint across the gulch its nearly vertical front is seen to be criss-crossed and deeply scored by joints and fractures and pitted with small caves. Its general tone is a somber gray, but here and there are patches and streaks of bright yellow and turquoise-blue, and the whole, framed by evergreen trees, forms a striking and beautiful picture. The North Fork of Cramer Creek heads just across the divide from Copper Cliff Gulch and flows in the opposite direction, the two valleys falling in line, a fact thought to be of importance in the interpretation of the structure. (See p. 217.)

GEOLOGY.

The rocks of the Copper Cliff district are a group of ancient sandstones and shales (Algonkian Belt series) and limestone (Cambrian) that normally overlies them. There are also a few small bodies of porphyry, but no other igneous rocks are known nearer than the head of Tenmile Creek, 2 miles away, where there is an outcrop of granodiorite. The sandstone is generally fine grained, thin bedded, and pale brown, drab, or red and shows a little fine white mica. It grades into shale on one hand and quartzite on the other. The limestone is fine grained, compact, and lead-gray, but weathers to lighter shades.

In general the sedimentary rocks of the Copper Cliff locality dip gently southwestward, for they lie well up on the southwest limb of an anticline that may be traced several miles in a northwesterly direction. At the Copper Cliff mine and in its immediate vicinity, however, all other structural features are subordinate to faults, of which the most prominent are within a belt 1,000 feet or more wide that trends northeast, coinciding with the courses of Copper Cliff Gulch and the North Fork of Cramer Creek. It is to be regretted that only the larger features of the faults can be described, because successful development of the mines depends more than anything else upon a detailed knowledge of the faults.

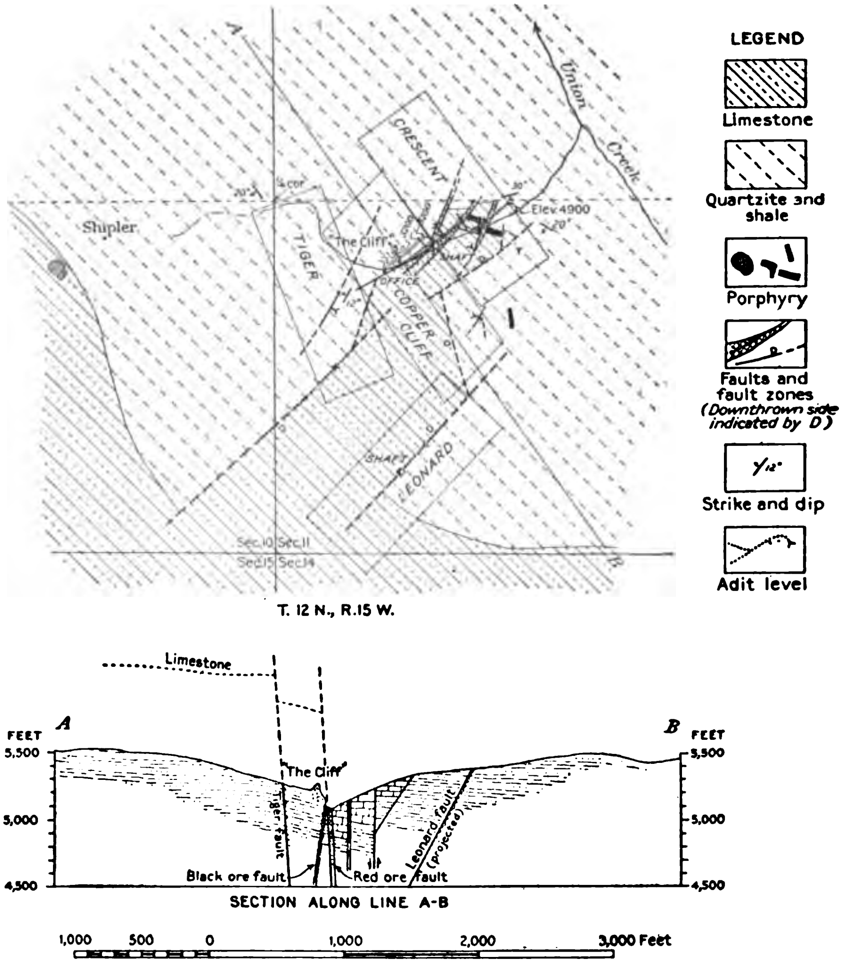


FIGURE 25.—Geologic map and section of the vicinity of Copper Cliff, Garnet Range, Mont.

The structure at Copper Cliff is shown in generalized fashion by figure 25. A large block of limestone is now wedged between opposing masses of the sandstone and shale that it formerly rested upon. Some parts of the limestone block are at least 1,000 feet below their original positions, others less, but all have been dislocated extensively. Most of the dislocation has been along fractures that strike N. 50° E.

and dip steeply to one side or the other, but movements have occurred along fractures of other directions, and as a result the limestone mass has an irregular zigzag outline. Apparently fractures are so numerous within the belt mentioned that the whole may be broadly viewed as a fault breccia. So far as the downthrow is concerned, the faulting appears to have been normal—that is, the hanging wall was dropped relatively. The rocks have been so severely crushed, however, that the mere dropping of a wedge-shaped block seems hardly adequate to account for their condition. Great pressure, such as may be conceived would be developed by a strong thrust causing extensive horizontal movements, is suggested by the general relations of the rocks. That this fault belt is a persistent structural feature is indicated by such evidence as the presence of breccia, the alignment of the North Fork of Cramer Creek and Copper Cliff Gulch, and a break in the continuity of the rocks for a considerable distance down the North fork of Cramer Creek. Apparently the most severe faulting has been in a relatively narrow zone on the northwest side of the limestone wedge and parallel to the face of the Cliff. Here underground workings expose at least three large fault fissures that contain from 10 to 20 feet or more of gouge and fine breccia. The principal slip planes in them have an average northeasterly direction and dip steeply one way or the other. As a rule none of them have well-defined walls, owing to cross fractures and the more or less crushed condition of all the rocks. One of them, however, appears to dip 80° NW. and the others at about the same angle in the opposite direction. On the southeast side of the limestone wedge a similar fault that dips 60° NW. and carries 10 feet or more of crushed material is shown at the Leonard mine. Other faults are less well exposed to examination, but unmistakable evidence of them is shown by practically all the numerous prospect pits. The Cliff itself is a mass of brecciated rock, which, unlike that of the faults just described, has been so tightly cemented that it is more resistant than even the quartzitic sandstone near by. Smaller masses of similar breccia occur at the Leonard and Tiger mines and elsewhere, all of which appear to have been shifted by fault movements. Workings that extend partly under the Cliff, although not carried far enough to prove that the brecciated mass is completely cut off, show plainly that it does not extend vertically downward, and that it is in all probability shifted greatly.

The evidence is clear that these cemented breccias are older than the open faults described and were doubtless produced by extensive earlier faulting or similar deformative movements. As distributed at present they do not trend in any particular direction, and the former course of the fault or faults that produced them is not known.

LODES.

CHARACTER AND COMPOSITION.

The fault breccias, both loose and consolidated, contain ore minerals and may be regarded as the lodes. So far as is known, the mineral-bearing portions of them are within an area not over half a mile long from southwest to northeast and a quarter of a mile wide.

The consolidated breccias are made up of angular fragments of fine-grained quartzite or silicified shale and a very abundant cement of quartz carrying more or less sulphides. The quartz appears more like flint or chert than that which ordinarily fills the veins of the region. The microscope shows it to be crystalline but extremely fine grained and containing shadowy outlines of rock fragments that it has replaced. Here and there are indistinct forms of radiated crystals suggesting that the quartz has gradually changed from the amorphous or opaline to the chalcedonic form. A large volume of this fine quartz was introduced throughout the mineralized area, but it did not invade the unbroken quartzite or limestone extensively.

Of the sulphides pyrite is as usual the most widely distributed and abundant. Part of it is of moderately coarse texture, and after it came into place it was broken and penetrated by veinlets of the flinty quartz and the minerals that came with it.

Enargite (arsenical sulphide of copper), an antimonial mineral that is probably famatinite (antimonial sulphide of copper), and pyrite, all generally occurring in microscopic grains, are intimately associated with the flinty quartz. Some crystals of enargite are coarse enough to be recognized with a hand lens, and here and there the mixture is rich enough in sulphides to be scratched with a knife, but commonly the material appears to the unaided eye as nothing more than a cloudy-black chalcedony. Even under the microscope the sulphides in some specimens appear as a dust clouding the quartz, the particles being so fine that their nature is determinable by chemical tests only. A little chalcocite was recognized in some specimens, but it does not seem to occur generally or abundantly in the deposits, and whether it is primary or secondary was not made out.

Oxidation has penetrated the consolidated breccias only a slight distance. Weathered surfaces show the usual iron and copper stains, and on the Cliff there are crusts of a bright-blue phosphate of copper. Some of the partly oxidized ore shows a little arsenate of copper, the mineral species of which was not determined, and crystals of pharmacosiderite (iron arsenate) were detected in vugs.

The metallic content of the deposits is irregular, and no very definite ore shoots have been located. A quarry face at the north end of the Cliff is said to average 2.5 per cent of copper, and selected small portions are evidently much richer. A carload of ore that averaged

22 per cent of copper is said to have come from a large boulder or detached mass found by drifting on the "black vein" 50 feet below the surface. As a whole, the Cliff probably does not contain more than 1 per cent of copper. At the Leonard and Tiger mines there is a consolidated breccia ore of a similar range in composition.

The loose or unconsolidated breccias are made up of soft, finely crushed material derived in part from the hard breccias and in part from the country rock. The principal workings in the Copper Cliff and Leonard mines are in oxidized loose breccias that contain abundant earthy iron oxides, malachite, and azurite. These bodies are large, but the limits and positions of the parts that may be regarded as ore are not known. Selected shipments have yielded 10 per cent or more of copper. In the red-ore vein at the Copper Cliff mine oxidation extends at least 150 feet below the bed of the gulch, but the adjacent black-ore vein, though fully as permeable as the other, is not oxidized even above the natural drainage level. Evidently these anomalous conditions were produced by recent faulting.

GENESIS.

From the foregoing data the history of the deposits is interpreted as follows:

Movements, probably faulting, crushed the rocks locally, making them open and easily traversed by water. Mineral-bearing solutions entering from below healed the fractures, cementing them with opaline quartz and at the same time introducing the sulphides. After the breccias had been tightly closed and cemented they were broken by strong northeasterly faults and subordinate fractures of other directions, repeated movements on which have extensively shifted the breccias and the country rocks and jumbled them all together. Oxidation commenced with this faulting and has continued to the present time, recent faulting having occurred also, as shown by downthrown oxidized material.

Enargite is not known as a mineral deposited from cold sulphate solutions, and nothing in its occurrence at Copper Cliff suggests that it has other than a deep-seated origin. In the mineralogy, and particularly in the texture of the quartz, the deposits at Copper Cliff are similar to certain ore bodies at Tintic, Utah, regarded by Lindgren[1] as replacements by "colloidal silica" that later crystallized to chalcedony and quartz. Enargite and other sulphides accompanied the silica, and these fine-textured bodies are at the outer end of a series of deposits clearly derived from intrusive granitic rock. Therefore it is thought that the Copper Cliff deposits have not been deeply cut away by erosion and may be reasonably expected to continue to a considerable depth, subject, of course, to shifting by faults. Furthermore, enriched ore is ordinarily to be expected below gossans such as the red-ore body at the Copper Cliff mine, subject again to having been moved or destroyed by faults. In fact, it appears that faulting is the chief drawback of these deposits, which otherwise show encouraging features. Doubtless in depth the rocks are less shattered and the faulting more uniform than in the loose superficial zone so far explored. An exhaustive study of the structure in the mineral-bearing area and adjoining territory, made hand in hand with the underground work, is absolutely necessary to the successful development of these somewhat unusual and promising deposits.

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[1] Lindgren, Waldemar, Processes of mineralization and enrichment in the Tintic mining district, Utah: Econ. Geology, vol. 10, pp. 225–249, 1915.

MINES AND PROSPECTS.

COPPER CLIFF.

The Copper Cliff mine is in the upper part of a short, steep gulch tributary to Union Creek from the southwest. In the bed of the gulch, at an elevation of about 5,100 feet, a shaft has been sunk 150 feet, and adit levels have been run toward it from points 300 and 700 feet downstream and respectively 80 and 200 feet lower. In addition a short adit is run northward from the gulch at a point 40 feet lower than the shaft collar, and there are several drifts and crosscuts, making in all about 1,500 feet of underground workings. The adits described as 40, 80, and 200 feet lower than the shaft collar are known, respectively, as Nos. 1, 2, and 3. The shaft and adit No. 2 are connected, but in September, 1916, adit No. 3, which was being driven toward the shaft, still lacked 300 feet of reaching a point directly beneath it.

The Copper Cliff lode was discovered about 1890 by W. P. Shipler and later purchased by an English company that did most of the development work described above. In recent years it has been idle most of the time, but in 1916 it was being further developed by Bielenberg & Higgins under lease and bond. Smelter certificates for the period 1905–1910 show a total of 310 tons of ore shipped to Tacoma, Wash., that yielded about 77,000 pounds of copper and a little gold and silver.

The formation is quartzite, shale, and limestone that have been faulted together, the limestone forming a downthrown block in which most of the mine workings have been made. In the lower adit and at some other places near by there are small blocks of porphyry, apparently broken from a dike or other intrusive body.

For a width of at least 1,000 feet the rocks bear evidence of repeated intense fault movements along northeasterly fractures. Locally the crushing and dislocations have been the most severe in narrow zones in which the rocks are ground almost to a pulp. Faults and slips of other directions are numerous but apparently not so extensive as the northeast ones. They show no general arrangement or grouping but serve to complicate the structure in no small degree. In addition there were older faults that became healed or cemented before the younger ones were made. They have been so obscured, however, by the later deformation that their courses and dimensions were not made out. The principal evidences of their existence are detached masses of breccia, of which the Cliff is the most prominent example. This interesting outcrop is situated on the west side of the gulch between the shaft and the company's office. It has a length of about 300 feet and rises 150 feet from the gulch channel. Its front, which has an average slope of 70°, faces the southeast. Other smaller masses of cemented breccia are found here and there, all apparently detached and shifted from their original positions by fault movements.

Most of the bodies of breccia and gouge, whether consolidated or not, contain more or less ore minerals and are regarded as the lode or lodes.

An open cut and a short adit made in the north end of the Cliff expose its structure very clearly. Angular fragments of pale-yellow and brown quartzite of different sizes are jumbled together and so firmly bound with an abundant tough fine-grained cement that the mass breaks more readily through the fragments than around them. Generally the cement is dark gray or black, affording a color contrast that makes the angular outlines of the quartzite fragments appear very distinctly. The cement is chiefly fine-grained quartz, and its color is due to very fine sulphides intimately mixed through it. Except that grains of pyrite can be easily recognized, the sulphide minerals are generally too fine or too thinly disseminated to be determined by ordinary methods. In places, however, they form rather pure masses the size of a hickory nut or larger, and in these enargite and probably famatinite can be identified. The same or similar minerals are doubtless present throughout the cement, because chemical tests show that it generally contains arsenic and antimony as well as copper.

Neither from the surface nor from joints and fractures has oxidation entered the mass more than a few feet, the rock being unusually compact and impervious. Where oxidation has occurred the usual iron oxides and green copper stains are seen. In addition there is a bright turquoise-blue mineral that forms crusts on weathered surfaces and gives the Cliff one of its striking color effects. Chemical tests show these crusts to be a phosphate of copper, the mineral species of which is not known. In places the face of the Cliff bears also a white incrustation that is one of the many phosphates of alumina.

The phosphorus is doubtless of animal origin, the cracks and caves in the Cliff being inhabited by the bushy-tailed wood rat, pack rat, or mountain rat, as it is variously known. The bright-yellow patches that contrast so vividly with the blues and grays on the face of the Cliff are not mineral, but growths of a lichen that is common in the general region.

Under the microscope the quartzite fragments are seen to be made up of sedimentary quartz grains, recrystallized and enlarged. The cement is a much finer textured crystalline quartz crowded with fine grains and specks of pyrite and the black sulphides mentioned. A small adit a short distance south of the Cliff, on the opposite side of the gulch, penetrates a mass of similar breccia, specimens of which contain broken pyrite, in which the fractures are filled with fine quartz-sulphide cement. In adit No. 3 there is a narrow body or vein of cemented breccia that strikes N. 20° W., dips 75° W., and cuts quartzite. It had been opened by a drift for a few feet, and so far as could be seen may not have been shifted greatly from its original position. In structure and composition it is similar to the rock of the Cliff but poorer in ore minerals. But little pyrite is present, and the copper minerals form a very light cloud in the cement.

The shaft and connected workings are in one of the zones of more recent intense faulting, 50 feet or more in width, that lies at the foot of the Cliff. At the shaft on the 80-foot level 20 or 30 feet of the zone is occupied by a rather soft earthy mass, chiefly oxides of iron in which films, flakes, and nuggets of native copper are scattered. Copper nuggets the size of walnuts are not uncommon, and one the size of a man's head is said to have been found. In addition, the red ore body, as the oxidized fault gouge is called, contains a few grains of unoxidized sulphide ore, quartz or quartzite, slight stains of copper carbonates, and a little gypsum that forms crusts in cavities. The body appears to have a southward pitch due to cross fractures or slips within the fault zone. A winze from the 80-foot level is said to have been sunk 70 feet without showing any notable change in the composition of the material. Here and there in adit No. 2 similar oxidized material is exposed. A crosscut that extends west from the shaft at a depth of 80 feet penetrates at a distance of 40 feet another intensely crushed zone, parallel to the red ore body, known as the "black ore." This body is simply a fault gouge 10 feet or more thick composed of finely ground country rock and sulphide ore, and its unoxidized condition is remarkable in view of the fact that it is freely open to the surface waters. Between the two ore zones there is crushed limestone, and beyond the black body a lead-gray shale also greatly broken by slips. The level ends at 120 feet in quartzite that is only slightly crushed and not at all mineralized, conditions that are surprising, because the huge mass of sulphide-bearing breccia known as the Cliff is directly overhead. Adit No. 1, which is parallel to the crosscut just described, penetrates a similar but wider body of black ore which is said to have yielded a larger boulder of rich sulphide ore. The dip of this black ore body or fault, as determined from its relative position in the two levels, is about 80° W. On the hillside opposite adit No. 2 workings have penetrated a small ore body that occurs near the surface in limestone and is chiefly a spongy mass of chrysocolla, partly altered to malachite and azurite. At the time of examination adit No. 3 had not reached a point beneath the red ore body. It passes from quartzite through a thick mass of crushed limestone and gouge, then through crushed porphyry, and ends in lime.

The different ore shipments from the Copper Cliff mine contained from 9.5 to 22 per cent of copper and from 0.5 to 1 ounce of silver and 25 cents to $2.30 a ton in gold. The richest shipment, 15 tons of 22 per cent copper ore, is said to have come chiefly from the large boulder of sulphide ore found in the black ore body about 50 feet below the surface. The other lots were selected chiefly from the red ore body but do not represent any large portion of it, and the average value of neither ore body is known. A large amount of material was recently quarried from the north end of the Cliff, average samples of which are said to assay about 2.5 per cent of copper. The Cliff as a whole, however, appears to be somewhat poorer, probably containing not more than 1 per cent of copper.

An attempt to hand pick or "cob" the material quarried from the Cliff proved that it can not be graded in this manner by any reasonable expenditure of labor. The rock is so tough and the sulphides are so irregularly and widely scattered through it, so fine, and so intimately mixed with quartz that anything like a clean separation of ore and waste is practically impossible. Because of the fine division of the sulphides, concentration by ordinary mechanical methods is also likely to be impracticable, but the material might yield to flotation.

LEONARD.

The Leonard mine, which lies about a third of a mile due south of the Copper Cliff and 400 feet higher, has been operated intermittently in recent years but was closed in September, 1916. It is said that 21 carloads of ore that assayed from 7 to 10 per cent in copper have been shipped from this mine to smelters. The principal workings are a shaft said to be 100 feet deep and, about 350 feet northeast of it, an incline. The lode occupies a northeasterly fault fissure that dips about 60° NW. and brings quartzite or shale and limestone into contact out of their normal sequence (fig. 25, p. 216). The fissure has a width of 10 feet or more and is filled with fragments of silicified breccia and earthy material like the red ore of the Copper Cliff mine. According to W. P. Shipler, one of the owners, the shaft passes through the lode at a depth of 50 feet, and the ore shipments were taken out above this level. The ore on the dump consists chiefly of compact and earthy iron oxides, through which stains and crusts of copper carbonates are scattered. Some small but beautifully developed crystals of malachite and azurite were seen, some specimens showing needles of azurite partly changed into malachite without a break in the continuity of the crystals.

At the incline, in addition to the soft ore described, there is several feet of partly oxidized breccia that contains enargite, famatinite, and pyrite and is otherwise similar to the material of the Cliff, at the Copper Cliff mine. In a collection owned by Mr. Shipler is a small but beautifully formed stalactite of green copper carbonate, one of several that were found in a cavity in the red ore at the shaft.

CLINTON DISTRICT.

HISTORY AND PRODUCTION.

The Clinton district is in the Garnet Range, a few miles northeast of Clinton, a town in the Clark Fork valley on the Northern Pacific and Chicago, Milwaukee & St. Paul railways. Most of the mines are within an area 5 or 6 miles long and 1 or 2 miles wide that begins 2 miles east of Clinton and extends northeastward across the divide and part way down the Blackfoot River slope.

About 1889 ore deposits were discovered in the northeastern part of the mineral-bearing area and several mines were opened that have produced a little ore from time to time. One of them, the Charcoal mine, is said to have yielded $15,000 in lead and silver. Between 1905 and 1912 considerable work was done on several groups of claims near Clinton, and some copper ore was shipped. From 1912 to 1916 the district was practically inactive, but according to reports received early in 1917 steps were either contemplated or being taken to reopen most of the mines. Estimates that include the principal mines only show a production prior to 1913 of about $25,000 worth of copper, lead, and silver.

Some of the mines and prospects were examined in 1911 by E. L. Jones, jr., to whom the writer is indebted for information about the northeastern part of the mineral area. Parts of the workings on three of the mines near Clinton were entered by the writer in November, 1912, and some additional facts were learned from the miners, but altogether the information at hand is not sufficient to allow a description of the district except in very general terms.

Timber and water are abundant in the Clinton district, the topography is such that many of the lodes can be worked through adit levels, and the wagon haul to the railroads is from 3 to 8 miles.

GEOGRAPHY.

The surface of the Clinton district is similar in general to the other portions of the Garnet Range described in this report. The general summit level ranges in height from 6,000 to 6,500 feet above the sea. Along both the main watershed and the prominent spurs from it there are flats or gently hilly surfaces at the elevations given. The rest of the land surface is steep and rugged because of the many deep, narrow valleys and gulches leading to the main drainage channels, which lie 2,500 feet or more below the general summit level. Part of the mineral-bearing area is drained southward by Wallace Creek, a tributary of Clark Fork, and the remainder is in the basin of Ashby Creek, which discharges into Blackfoot River. Between Ashby Creek and a branch of Wallace Creek there is a rather narrow pass at an elevation of 5,400 feet, through which the road goes from Clinton to Potomac.

GEOLOGY.

Most of the mineral-bearing area is occupied by an exposure of granodiorite 5 miles long and from half a mile to a mile or more wide. That this intrusive body is uncovered only in part is shown by its outline, which commonly expands where crossed by gulches and contracts on the intervening spurs. In general appearance and composition the granodiorite is similar to that exposed at Garnet and elsewhere in the general area under consideration. As a rule the rock is light gray and even grained, showing feldspar, quartz, hornblende, and mica, but in places near the margin of the mass it shows porphyritic feldspars in a groundmass somewhat darker than usual.

In the granodiorite area and that of the metamorphic rocks around it there are loose fragments of a dike rock similar to the granodiorite porphyry observed at Garnet.

Quartzite, shale, and limestone of the same age and general character as those at Garnet, Copper Cliff, and elsewhere surround the granodiorite and have been metamorphosed by it. Generally the quartzite shows abundant mica, and in places the rock is mottled in pale green or brown, owing to very fine micas being gathered in clusters. Some of the shale is changed to a tough green-banded hornstone, and the limestone is crystalline, resembling a coarse-grained marble. As a rule the evidences of contact metamorphism are very plain to a distance of 500 feet from the contact, and may be detected here and there as far away as half a mile.

The principal structural feature is a large trough or syncline that involves the sedimentary rocks and has lowered a belt of limestone across the northeastern part of the district. On both sides of this fold the quartzite and shale are steeply inclined and are probably deformed by other parallel folds also. Faults are seen in some of the mines, but nothing is known of their structural importance.

LODES.

Lodes are found throughout the granodiorite body and in the metamorphic rocks around it. Most of those in the granodiorite are valuable chiefly for copper and subordinately for silver and gold, and those in the sedimentary rocks, particularly the limestone, contain lead and silver. Considerable amounts of lead are known also in some of the lodes in granodiorite, and copper is generally present in the lodes in the other rocks, particularly near the contact.

The most extensively developed lodes are along Wallace Creek and its tributaries Trail and Woodville creeks, about 2¼ miles east-northeast of Clinton. Within a square mile there are 50 or more mines and prospects, on some of which the workings reach a depth of 500 feet vertically below the surface. Another numerous group is in the northeastern part of the mineral-bearing area in the basin of Ashby Creek, and although prospects are by no means scarce in the rest of the area few of them have been worked to any extent.

Most of the lodes in granodiorite, and doubtless some of those in the other rocks, are composite veins or shear zones, each of which is made up of several parallel fractures, together forming a sheared or broken zone from 1 foot to 20 feet or more in width. Commonly the fractures are closely spaced and the intervening rock more or less crushed. The lodes or zones apparently do not depart far from a N. 40° E. strike, and most of them dip steeply northwest. Some are cut and displaced by transverse faults. Many of the individual fractures contain ore seams or veinlets that are generally less than an inch thick but locally may be a foot or more thick for distances of several feet. The most valuable ore bodies, however, are those portions of the sheared zones in which the small ore seams are so numerous and close together that the whole is rich enough to mine. The dimensions and richness of these stringer lodes are known in part only, carload shipments and samples that are said to represent widths of several feet having contained from 1.5 to 6 per cent or more of copper and $2 to $10 a ton in gold and silver. As far as the rather meager available information shows, ore from levels above a depth of 300 feet is partly or wholly oxidized and generally twice as rich as that from lower levels.

The primary minerals are chalcopyrite, bornite, specularite, ankerite, calcite, quartz, and possibly also chalcocite, all of which were introduced from below, filling the fractures and replacing the wall rock. In addition barite, strontianite, and a bismuth mineral are reported. In the oxidized zone the usual copper carbonates and iron oxides occur.

In the northeastern part of the mineral belt there are composite veins similar to those described, and also lodes of irregular form developed at the contact or in the metamorphic rocks adjoining it. So far as known, the lodes in granodiorite are similar in composition to those nearer Clinton, except that some of them contain noteworthy amounts of silver-bearing galena and a little zinc blende. As a rule the lodes in the sedimentary rocks, particularly the limestone, are valuable chiefly for lead and silver, their most abundant metalliferous minerals being galena and cerusite. Zinc blende was observed in some of them, and calcite and quartz are the chief gangue minerals.

The geologic relations and composition of the lodes, particularly the occurrence of chalcopyrite and specularite together, suggest that they were formed by hot solutions from either a deep-seated portion of the granodiorite body or a later intrusive rock not yet exposed.

Lead and copper appear for the most part to be arranged in zones one above the other. Galena is most abundant in high situations, either in the top of the granodiorite body or in the rocks that inclose it. A thousand feet down in the intrusive mass, which is about the relative position of the workings in the Triangle and other mines near by, chalcopyrite is the most abundant ore mineral and galena or other ores of lead are absent. The fracture zones appear to be strong and persistent, there is no reason to think that the copper minerals do not continue to considerable depths, and in view of all the information available the prospect seems bright, at least as long as the metals maintain their present (1917) high prices, for the development of large ore bodies.

MINES AND PROSPECTS.

In addition to the mines described farther on, there are in the district a large number of claims or groups of claims which are not described in this report but which from all accounts are worth exploring. Among those near Clinton are the Hidden Treasure, Senate, Aladdin, and Crawford groups, on each of which considerable work has already been done. In the northeastern part of the mineral belt are the Charcoal, Gowrie, Adaline, Sumpter, Daisy, and Nellie, most of which have produced some shipping ore.

CAPE NOME.

The Cape Nome mine is on the east side of Trail Creek, about 3 miles east of Clinton. Prior to 1912 the mine was extensively developed, and ore shipments that yielded about 19,000 pounds of copper, 2,000 ounces of silver, and $100 in gold are reported by the owners.

The workings, which are in granodiorite, are said to consist of two adit levels and a shaft 500 feet deep from which several drifts and crosscuts are run, aggregating in all more than 4,000 feet of underground work. Two lodes have been explored that strike about north, dip 60° or more to the west, and are cut and displaced by vertical northeasterly faults. They are described as composite veins or shear zones 4 to 10 feet wide, in which there are lenslike bodies 2 feet in greatest thickness composed of quartz, barite, chalcopyrite, tetrahedrite, and chalcocite. Oxidation is partial or complete to depths that range from 100 to 300 feet.

Smelter certificates for the shipments mentioned above, which are said to have been made up of mixed sulphide and oxidized ore from different parts of the mine above the 300 level, show that the copper content ranged from 1.6 to 12.7 per cent, the gold from 20 cents to $4.50 a ton, and the silver from 5 to 20 ounces a ton. On the average the ore contained 63 per cent of silica and 12 or 15 per cent of ferric oxide or its equivalent. On the 500 level the vein for a width of several feet is said to average 2.5 per cent of copper and 6 ounces of silver to the ton, the silica and iron contents being 55 and 15 per cent, respectively.

TRIANGLE AND GRASS WIDOW.

The Triangle and Grass Widow mines are about 2½ miles east-northeast of Clinton, on Woodville Creek, a small west branch of Wallace Creek. In 1912 the Triangle had been developed by an adit level driven 540 feet on a N. 40° E. course into a steeply rising granodiorite hill. This working follows a composite vein or zone of parallel fractures that is 10 feet or more in width and dips 75° NW. Ore shipments, in which copper was the most valuable constituent, are reported to have yielded about $3,500.

Most of the fractures that make up the zone contain ore seams that are generally less than an inch in width and in places are rather numerous and closely spaced. The intervening granodiorite is moderately crushed and extensively bleached and sericitized. Near the face of the adit, where several branch fractures lead off to the north, there is a fairly rich looking ore body 14 inches wide and 40 or 50 feet long. The vein filling consists of specularite, chalcopyrite, ankerite, calcite, and quartz, all intergrown. In the oxidized zone penetrated by the first part of the adit there are the usual carbonates of copper and oxides of iron. Smelter certificates for the shipments mentioned show from 3.5 to 6.75 per cent of copper and 7 to 13 ounces of silver and $1.50 to $2.50 in gold to the ton.

The Grass Widow lode is parallel to the Triangle and about 600 feet to the northwest. It is explored at a depth of about 500 feet by drifts reached through a crosscut from the Triangle adit level. There are two main seams about 40 feet apart containing ore similar to that in the Triangle.

JACK POT.

The Jack Pot mine is on the west side of Trail Creek near its junction with Wallace Creek, 2 miles east of Clinton. In 1912 an adit had been driven N. 40° E. for 300 feet in granodiorite, following a composite vein or shear zone that dips about 75° NW. A small dike of granodiorite porphyry, which together with the granodiorite is bleached and sericitized, has been intruded along the shear zone. The fractures contain thin seams of chalcopyrite, specularite, ankerite, and quartz, or minerals derived from them by oxidation, and the zone is otherwise similar to those in the Triangle and Grass Widow claims. In places a little chalcocite fills cracks and also partly replaces the chalcopyrite.

OUTLYING MINES AND PROSPECTS.

Outside of the districts described in this report there are isolated mines and prospects more or less worthy of notice, in particular near Garnet, Coloma, and the head of Elk Creek. Most of them are quartz veins in granodiorite or quartzite and are presumably valuable for gold. One on a knob half a mile south of Coloma shows a little galena and tetrahedrite in silicified limestone.

Here and there along the limestone summits from Mulky Creek to Clinton are scattered deposits of silver-lead ore, of the irregular or pockety form usual to ore bodies in limestone, from some of which ore has been shipped. In addition to those described below, a prospect of Otto McQucston, on the divide north of Tenmile Creek, has made a small production.

Copper prospects, none of which, however, show any great promise, occur at wide intervals. One on the West Fork of Cramer Creek, known as the Gypsy, is on a loose fault breccia of quartzite stained with copper carbonates at the surface and showing a little chalcopyrite below. Another, the Ophir, situated on Tyler Creek a mile south of Clark Fork, occurs in an intrusive sheet or sill of gabbro and is a sheared zone containing nodules of chalcopyrite.

CHLORIDE.

The Chloride mine, on the main divide, 3 miles southwest of Copper Cliff, is a lead-silver deposit from which a few ore shipments are reported. The country rock is a dark-gray or blue limestone (Devonian Jefferson limestone), much higher in the sequence than the limestone at Garnet and Copper Cliff. Along one or more zones of a general northwesterly direction, in which the rocks were fractured or crushed, the limestone has been extensively replaced by silica, being converted into a yellow or brown jasper. Within the area of a quarter section several ore bodies have been found, most of which have a pipelike form, stand vertically or inclined, and are 3 or 4 feet in diameter and 20 feet or more in length. All are closely associated with fracture or joint planes and surrounded by the jaspery quartz. The ore is a fine-grained galena, more or less altered to carbonate.

Loose boulders of similar ore are shown in a prospect pit in limestone about a mile west of Copper Cliff.

BAKER & SULLIVAN.

About $11,000 worth of lead-silver ore is reported to have been shipped by Baker & Sullivan from a mine at the head of Mulky Creek, about 4½ miles in an air line southeast of Garnet. This mine has been idle for a number of years. Several open pits and shafts are made on a ridge near the head of Mulky Creek canyon, at an elevation of 6,600 feet. The country rock is limestone of the same age (Cambrian) as that at Garnet and Copper Cliff and is exposed along the summit of a northwesterly anticline.

Along a fractured zone caused apparently by the folding of the beds silica has replaced the limestone extensively and ore pockets have formed. The principal ore body mined has the cross section of a lens 3 or 4 feet thick and 30 feet or more in diameter. The ore is chiefly ocherous material containing galena and its oxidized products, among which cerusite and massicot were identified. There is also a little copper stain. Under the microscope a thin section of the silicified limestone, a yellow or brown jaspery rock, showed a dust of iron oxides and some small crystals of garnet distributed through fine-grained quartz.

MORSE & KENNEDY.

A small ore shipment is reported from a mine formerly worked by Morse & Kennedy, half a mile north of the junction of Elk Creek and its north fork. An open cut at an elevation of 4,650 feet is made at the contact between granodiorite and limestone, and about 50 feet lower an adit level is driven 200 feet or more through granodiorite into the limestone. The contact plane, which is very uneven in detail but is on the whole nearly vertical, bears an irregular deposit consisting of coarse-grained brown garnet, epidote, calcite, and quartz. There are also flakes of specularite and scattered grains and nodules of chalcopyrite inclosed in calcite and intergrown with the silicates mentioned. The deposit is partly oxidized, showing limonite, malachite, and chrysocolla. The copper minerals are mostly confined to a layer that is 3 or 4 feet thick in the open cut but apparently pinches out in the adit below. This deposit is similar in character and origin to the contact-metamorphic bodies at Top o' Deep, but it lies relatively farther down on the sides of the intrusive body, a condition that is thought unfavorable to its downward persistence.

Farther south along the contact in a prospect near Elk Creek there are small seams and pockets in limestone containing chalcopyrite and gray copper.

PLACER DEPOSITS.

HISTORY OF MINING.

Bear and Elk creeks are among the more productive localities of early placer mining in Montana. Gold was discovered here in 1865, the usual rush to the new diggings took place, and, as claims were then restricted to a length of 200 feet, the gulches were soon alive with miners. The pay streak was narrow but rich and favorably situated for drifting, and when the individual workings became connected it is said that one could walk 8 or 10 miles underground up Bear Creek and its main tributary, Deep Creek, without once coming to the surface. At the mouth of Deep Creek, Beartown, celebrated as one of the wildest of the wild early-day mining camps, became the trading center for a population estimated at 5,000 or more. Other thriving camps were Springtown, farther up Deep Creek, and Reynolds City, near the head of Elk Creek. An idea of the cost of supplies at the time is shown by a Reynolds City storekeeper's account which is among the relics preserved by Larabie Bros., bankers, at Deer Lodge. Under the date May 4, 1866, potatoes are charged at the rate of 12½ cents, salt 50 cents, sugar 75 cents, nails 25 cents, and bacon 80 cents a pound. Wages were correspondingly high, and most of the ground that would pay to work under such conditions was exhausted in three or four years and the miners went almost as suddenly as they came. Only a few abandoned cabins remain at Beartown, and the other camps are almost completely obliterated. Since the mining activity declined some of the claims have been reworked from time to time, and new ground that was too lean or otherwise unsuited to early-day methods has been opened. In 1916 open-cut or hydraulic mining was done in a rather small way in about half a dozen places on Bear and Elk creeks.

PRODUCTION.

During the period of greatest activity few of the miners kept records of production, and as gold dust was in general use for currency, that from Bear Creek soon became mingled with gold from other sources, all traveling many devious paths before reaching the banks or the mint. That the total, however, runs well into millions is generally believed and strongly supported by the data available. The linear extent of the ground mined along Bear Creek and its tributaries, together with that in Bilk and Weasel gulches, is at least 20 miles. According to trustworthy reports, one claim below Top o' Deep yielded $240,000, or at the rate of $1,200 a running foot. Comparably rich also were a claim at the mouth of Cayuse Gulch and portions of First Chance Gulch and its tributary, Williams Gulch. Other claims here and there yielded smaller amounts down to $10 a foot, which was doubtless about the limit for profitable mining at that time. Exclusive of the exceptionally rich spots mentioned, the general average is about $50 a running foot, equivalent to $250,000 a mile, or a total of $5,000,000, which is thought to be a safe minimum for the drainage basin of Bear Creek. Probably $7,000,000 or more, the estimate made by persons living in the district, is nearer the true total. For Elk Creek even less definite data are available, but the extent of the old workings shows that the production must have been large. Estimates by persons familiar with the mining history of this stream range from $1,000,000 to $2,000,000 or more, and the total placer production of the whole area is doubtless somewhere between $6,000,000 and $10,000,000.

DISTRIBUTION AND CHARACTER.

Placer deposits are distributed along Bear and Elk creeks and all their tributary gulches which head in the area between Top o' Deep and Coloma. Bilk and Weasel gulches, which discharge eastward from Top o' Deep, and Washoe Gulch, leading west from Coloma, are also gold bearing, but their deposits do not extend very far downstream. In addition, there are less extensive deposits on a bar at Bearmouth and in Felan and Tenmile creeks. A very little gold is found all along Clark Fork, and small amounts are doubtless present in most of the other streams, but except those enumerated above no workable deposits are known in the region covered by this report.

The bulk of the gold taken from Bear Creek is in particles smaller than wheat grains, and of various shapes from flakes to shot. Nuggets are fairly numerous and of various weights; the heaviest reported weighed 32 ounces. Some of the nuggets are intergrown with quartz, and most of the larger ones were found near the heads of the gulches, where also much of the gold is rough or ragged. Farther downstream the particles average smaller and are generally smoothed, though still irregular in shape. Most of the Elk Creek gold is flat, almost flaky, and the particles average somewhat smaller than in Bear Creek.

Except in the bar at Bearmouth the gold along Clark Fork is sparsely but widely distributed as flakes, some of them as broad as a pin head but so thin and light that the largest will hardly turn the most delicate balance. Doubtless several hundred of them would be required to make 1 cent.

The gold of Bear and Elk creeks is deep yellow and its surface varies from bright to rusty, the shade being significant chiefly of the length of time the particles may have lain in the gravel undisturbed.

The fineness or purity of the gold does not range far from 0.900—that is, of 1,000 parts by weight 900 are pure gold and the remainder alloy, chiefly silver. Records kept by the late E. S. Larabie, of Deer Lodge, show an average of 0.906 for both Bear and Elk creeks, but the data are insufficient to determine whether, as in many placer deposits elsewhere, there is a gradual increase in fineness downstream.

Part of the gold is found in joints and cracks a foot or two deep in the bedrock, and the remainder is distributed through a thin layer of gravel above, the gravel and gold-bearing bedrock together forming the "pay streak." The main pay streak in Bear Creek is in the channel or lowest portion of the bedrock surface and, although 50 feet or more wide in places, generally is not over 10 or 15 feet wide. On top of it is 20 to 50 feet of overburden that consists largely of detritus from the hillsides above, the separation between the pay streak and the valueless material being as a rule rather clean and sharp. Along the smaller tributaries the overburden is less and the pay streak not so well defined, particularly near the heads of the gulches, where it commonly widens and grades into the hill talus or surface mantle on each side. Another pay streak similar to that described except that it is not continuous is found in bars along both sides of Bear Creek 50 to 100 feet above the stream. The Elk Creek pay streak is similar to that in Bear Creek except that it is less deeply buried and not so well defined. Bars are extensive along the west side of the stream in the vicinity of Sunset, but are not known upstream. For the most part the gravel of the pay streaks does not contain large boulders, is but moderately waterworn, and is rather firmly packed. The amount of sand is rather small in Bear Creek and large along Elk Creek, where also particles of magnetite, ilmenite, and other dark heavy minerals collectively known as black sand are abundant. In the mine of B. A. C. Stone a gravel of unusual type, which contains waterworn cobbles completely softened by decay, occurs at the summit of the mountains.

Along Bear Creek few lean spots were found in the pay streaks, and in places the gravel yielded as much as $1,000 a cubic yard, according to all reports. A general average based upon the rather meager available data is $30 a yard. Elk Creek is not so rich on the average, but there are places, particularly in its tributary gulches, comparable to Bear Creek. The bars near Sunset were fairly rich, and a body of workable gravel is thought to lie beneath the flat valley of Elk Creek opposite.

Unsuccessful attempts to mine the scale or leaf gold along Clark Fork have been made on a bar below Nimrod and elsewhere.

Placer deposits occur along the stream beds and in low bars in Tenmile and Felan creeks, but they are not comparable in extent or richness to the deposits of Bear Creek. Along these streams the most extensive mining has been done in a small basin about a mile up Felan Creek and in gulches from a low divide between that stream and Tenmile Creek. The gold produced is said to be of the same quality but less waterworn than that from Bear Creek.

ORIGIN.

The distribution of the gold leaves no room for doubt, except as to Felan and Tenmile creeks, that the placer gold came from the quartz lodes in the Garnet and adjoining districts. After the quartz lodes had been formed erosion reduced the land to a generally flat surface, the peneplain described under the heading "Physiography" (pp. 162–165), which doubtless was low with reference to the sea at the time. The lodes were exposed, their upper portions were worn away, and the gold was incorporated in stream gravel, of which that at Stones Flat and probably in part that in Williams Gulch and other high, flat valleys are remnants. Owing to the flatness of the land the streams of that period were sluggish and unable to shift the gold very far from its place of origin. The great changes that have taken place since then, both in the form of land and in the distribution of the gold, are due primarily to a general uplift of the region, as a consequence of which the multitude of deep gulches and narrow valleys of to-day were excavated, and the gold carried down the narrow channels far from its source. The uplift, however, was somewhat complicated by warping of the surface and the outpouring of lavas, as more fully described in the section on physiography. Necessarily the drainage system underwent many changes. Some of the streams, such as the one which built the gravel bed at Stones Flat, were cut off, their water becoming parceled among other streams and their identity lost. When Bear and Elk creeks had sunk their valleys within short distances of their present depths they ceased down-cutting long enough to widen their valleys slightly and deposit considerable gravel. Remnants of this deposit left here and there when the streams had cut to their present depth form bars, such as Archers and Simpsons bars on Bear Creek and the bar along Elk Creek near Sunset. The bars along Bear Creek correlated with some low bars or terraces along Clark Fork, described in the section on physiography, were probably caused by a temporary damming of the drainage farther down. At present Clark Fork is temporarily (in a geologic sense) interrupted in its down-cutting by a dam of glacial outwash at Bonner, and its valley has become deeply floored with gravel. Necessarily most of its tributaries have ceased to deepen along their lower courses, and considerable loose material, such as the overburden of the pay streak in Bear Creek, has accumulated.

CONCLUSIONS.

Placer mining along Bear Creek and its branches has declined to a comparatively insignificant stage, although there is a possibility that it may be revived somewhat by hydraulic or open-cut mining. On Elk Creek some open-cut mining is done, there is considerable unworked ground remaining, and along the flat part of this stream near Sunset a fairly large area may prove to be worth dredging.

MINES.

STONE.

A gravel deposit mined by B. A. C. Stone at Stones Flat on the divide between Cayuse and Day gulches presents some unusually interesting features. At this locality the main divide is a level flat 1,500 feet wide having an elevation of 6,250 feet. On the east and west it merges with rather gentle slopes that rise a few hundred feet, but to the north and south it is rather abruptly terminated by steep descents. An open cut at the south side exposes a bed of compact red sandy clay 30 feet deep to bedrock. Mingled with the clay are small fragments of a rather impure micaceous quartzite, many of which are so thoroughly decomposed that they fall to pieces at a touch. The lowest layer of the deposits contains smooth waterworn cobbles of soft quartzite as much as 6 inches in diameter. The bedrock, which slopes gently southward, is of similar quartzite, smoothed and waterworn and likewise softened to the depth of a foot or more. Evidently the deposit is very old, the stream that made it was long ago diverted to other channels, and the topography of that time has been greatly changed.

Owing to the scantiness of the water supply mining operations are conducted on a small scale, but nevertheless the ground is said to repay working. At the face of the cut the pay streak is 50 feet wide, and presumably it extends across the flat. The gold occurs mostly in small particles, that do not differ in appearance from the placer gold elsewhere in the district. The erosion of quartz veins that crop out around the flat doubtless supplied the gold.

LEHSOU (HICKEY).

Placer mining, restricted by the water supply to small operations, was done in 1916 by Patrick Hickey on the Lehsou mine, at the head of Deep Creek, just above the old placer camp known as Top o' Deep. Deep Creek rises in a small, rather shallow basin at an average elevation of 6,200 feet. In the center of the basin a pit about 600 feet in diameter forms one end of the more or less connected chain of workings that extends throughout Deep and Bear creeks. The bank surrounding this pit ranges from 5 to 20 feet in height and is composed of material loosened from the underlying rocks by weathering and moved downhill slightly by gravity. No stream-washed fragments were observed, although the deposit has been slightly channeled and doubtless helped in its downward movement by rain and snow water. The bedrock is granodiorite, containing many outcrops of small gold-bearing quartz veins and broad zones of a rusty material that is said to be gold bearing also. The gravel contains irregularly distributed but appreciable amounts of placer gold, although mining with the scanty supply of water is hardly profitable. Doubtless much of the ground surrounding the pit, particularly the slopes to the east and north, would pay to work if water were readily available.

The gold is rough but not ragged and ranges in size from dust and small particles to nuggets weighing several ounces. Vein quartz adheres to most of the nuggets, one recently found being a quartz fragment the size of a hickory nut, in which an irregular mass of gold weighing an ounce or more is embedded. This quartz is fine grained, compact, and rather dull milky white in color, similar to the quartz of many veinlets exposed in the bedrock.

BILK GULCH.

Although Bilk Gulch has ceased to be productive, its later history and some of its natural features are of more than ordinary interest. To wash the gold-bearing material, which extended practically to the divide between Bilk and Deep gulches, at an elevation of 6,550 feet, a pumping plant was installed by King, Allen & Preston, on Weasel Creek, somewhat more than a mile to the east and about 800 feet lower. Water was pumped through a pipe to an elevated point and conveyed by a flume to a large planked reservoir above the ground to be worked. The total cost of the pump, pipe line, and tank is said to have been nearly $70,000. The gravel was washed, and proved to be rich, yielding a large amount of gold, but financially the venture was a failure, because the deposit was exhausted before production had equaled the cost of the plant.

Gravel mined along the lower course of Bilk Gulch at an earlier date by G. W. Morse was rich, and several nuggets were found, one of which weighed 32 ounces, equivalent to a value of about $600. Large boulders of brown garnet rock are abundant among the débris of the old mine workings, especially along the upper part of the gulch. When broken, some of them show small particles of gold associated with chrysocolla. The boulders are evidently residual from contact-metamorphic bodies, of which several crop out conspicuously near the head of the gulch.

WARNER (ELK CREEK HYDRAULIC MINING CO.).

A placer mine on Elk Creek, 2 or 3 miles southeast of the locality known as Sunset, is owned by the Elk Creek Hydraulic Mining Co. and operated by W. W. Warner. At the mine the valley of Elk Creek is a narrow V-shaped trough with steep slopes about 700 feet high. A short distance upstream the valley flares somewhat, and about a mile downstream it opens into Sunset Valley, a wide basin crossed by Blackfoot River.

Below the North Fork of Elk Creek quartzite and indurated shale (Belt series) crop out on the slopes and evidently form the bedrock beneath the stream gravel. At the North Fork the quartzite and shale are cut off by a granodiorite body that extends up the main stream to its head.

The principal working is an open cut dug upstream 1,000 feet or more and equipped with a 30-inch flume and a steam derrick for moving boulders. In September, 1916, ground sluicing was in progress and the face of the cut was about a quarter of a mile below the North Fork. Owing to the slight average fall of the creek, about 6 inches to a rod, at this locality, the flume could not be given sufficient grade to carry any but the smaller rocks or prevent the sand from packing. From the writer's experience it is suggested that a wider flume would work better, but it is always difficult, if not impossible, to prevent sand from packing in a flume of slight grade. Formerly a hydraulic elevator was used at this mine for lifting tailings, but it was abandoned because of the excessive cost of its operation and upkeep.

At the face the cut is said to be within 2 feet of the bedrock. Here the bank is made up of a 4-foot layer of rather loosely packed stream gravel containing numerous boulders 2 feet or more in diameter. Above this are 5 or 6 feet of fine gravel and silt and a top layer of tailings, mostly sand, washed from the old mines above. A considerable portion of the sand that collects in the flume consists of magnetite, ilmenite, and particles of hornblende and other dark minerals derived from the granite.

The gold occurs mainly as dust and small flat particles, few of which are more than one-sixteenth of an inch in diameter, and most of it is confined to a foot or two of gravel next the bedrock. The cut is said to have repaid working expenses so far, but the yield was not learned. The deposit no doubt is valuable, because Elk Creek has yielded richly farther up, and gold is known below. The unworked ground extends 2 miles or more above the workings described.

POWERS.

Mining in a small way is done by Patrick Powers on Elk Creek at the mouth of Jonathan Gulch. Here some comparatively small blocks of unworked ground remain, situated mainly on the sides of the main pay streak, which was worked out in former years. The gravel is 8 feet deep and contains a moderate number of boulders, and the gold is found mostly as rather fine, flat particles on the granite bedrock.

M'KEVITT & IVERSON.

A block of new ground on Elk Creek at the mouth of McManus Gulch was being opened by McKevitt & Iverson in 1916. An open cut, worked by ground sluicing through a 16-inch flume, has been made to bedrock. The bank is from 10 to 18 feet deep and is mostly sand and medium-textured gravel. There are a few large granite boulders.

WILLIAMS ESTATE.

Stretches of several miles of the main channel along Bear and Deep creeks are covered by patented claims, owned by the Williams estate, that were inactive in 1916 but were formerly worked by drifting. Although the pay streak is generally narrow and sharply separate from barren material, this ground may repay hydraulicking in places, for the early-day drift miners commonly left more or less gold behind them.

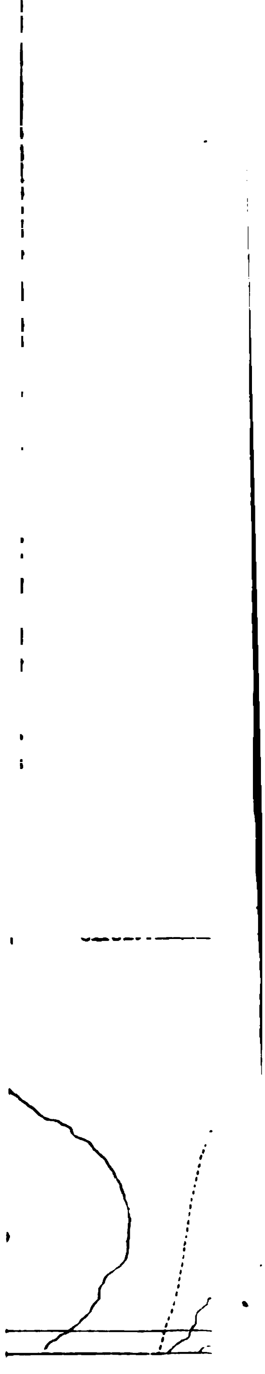
LANNEN.

Bear Creek has not been drifted for a distance of half a mile above its mouth owing to difficulties in the way of drainage. The rich pay streak worked farther up presumably continues down to Clark Fork, buried by 100 feet or more of valueless gravel. So far as known no recent attempts have been made to work this ground, but conceivably it might be drained by pumping.

A bar at Bearmouth, south of Clark Fork and 100 feet above it, was profitably mined several years ago by John Lannen. The deposit is mostly river gravel, but it also contains rather large boulders, which, together with the gold, apparently came from Bear Creek, and it is thought to be correlated with the bars of that stream. Some patches of unworked gravel remain.

TENMILE.

Near the junction of Tenmile and Bear creeks there is considerable new ground which is thought to be valuable, which was being opened for hydraulic or open-cut mining in 1916.



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THE DUNKLEBERG MINING DISTRICT, GRANITE COUNTY, MONTANA.

By J. T. Pardee.

LOCATION.

The Dunkleberg district is in northeastern Granite County, Mont., about 50 miles northwest of Butte. (See fig. 16.) The mines and prospects are confined to an area 2 miles wide and 5 miles long, near the north end of the Flint Creek Range. From Hall, a town on the Philipsburg branch of the Northern Pacific Railway, the mining area is reached by a road that goes southeastward up a low spur known as Limestone Ridge. There is also a road, formerly used for hauling ore, that goes up Dunkleberg Creek from Jens, a station on the Northern Pacific main line.

FIELD WORK AND ACKNOWLEDGMENTS.

A brief reconnaissance of the mining area was made in June, 1916, by the writer, assisted by T. H. Rosenkranz. For courtesies extended in the field the writer's thanks are due to Messrs. Walter Neal and Albert Hollander, in charge of the Wasa mine. Acknowledgment is made also to W. T. Schaller, of the Geological Survey, for the laboratory determination of several minerals.

HISTORY AND PRODUCTION.

In the Dunkleberg district lode mining has been carried on intermittently during the last 30 years, and at one time smelting was tried on a small scale. In June, 1916, a deposit of zinc ore in the Wasa mine was being systematically explored with a diamond drill and a few other claims were being developed in a small way. The total production of the district is roughly estimated at $200,000 or more in silver and lead.

TOPOGRAPHY.

The mining area, which is in the northern foothills of the Flint Creek Range, has a rather uniform general slope toward the north, descending about 2,000 feet in 5 miles. In distant views the surface appears rather smooth, its most prominent feature as seen looking east from the Flint Creek valley being Dunkleberg Ridge, a long spur marked by some rather conspicuous knobs, which forms the extreme north end of the Flint Creek Range. A topographic feature which occupies a considerable part of the mining area, but whose rugged character is not apparent except at close range, is the valley of Dunkleberg Creek. This drainage channel, which lies east of Dunkleberg Ridge, heads in a small, deep glacial cirque at the south and throughout its course northward across the mining area is 1,000 feet deep, narrow, and very steep-sided.

GEOLOGY.

The mining area is occupied chiefly by sandstones and shales of Cretaceous age. At the south end of the mineral belt on Dunkleberg Ridge there is a small area of Carboniferous quartzite and shale (Quadrant and Phosphoria formations) and Jurassic sandstone, shale, and limestone (Ellis formation). To the north these beds dip beneath Lower Cretaceous shale and limestone (Kootenai formation), which are exposed at the Wasa mine and which in turn are overlain by thick Upper Cretaceous shales, sandstones, and conglomerates (Colorado and Montana? formations). The most useful of these rocks as a base from which to determine the stratigraphic sequence is a limestone bed about 100 feet thick that occurs near the top of the Kootenai formation and is generally crowded with small fossil snails or gastropods. At the Forest Rose mine the fossils in this limestone are very abundant and conspicuous, but farther south, owing to contact metamorphism, they are not well preserved. The outcrop of this bed forms a loop that enters the district on the south, includes the Wasa mine, and extends northeastward, ending in a long narrow point a short distance beyond the Forest Rose. (See Pl. X.)

In the shales and sandstones above the gastropod-bearing limestone there are several sills of a heavy dark greenish-gray crystalline rock. Their aggregate volume is large, particularly east of Dunkleberg Creek, where some of the individual sills are 1,000 feet or more thick. From this locality they can be traced 25 miles eastward to a point near Avon, and apparently they were intruded throughout an area of at least 300 square miles. A specimen from one that crops out east of Hoover Creek and north of Clark Fork proved, on microscopic examination, to be gabbro.[1] Others from the sills in the basin of Gold Creek are diorite.[2]

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[1] Pardee, J. T., The Garrison and Philipsburg phosphate fields, Mont.: U. S. Geol. Survey Bull. 640, p. 212, 1917.

[2] Emmons, W. H., and Calkins, F. C., Geology and ore deposits of the Philipsburg quadrangle, Mont.: U. S. Geol. Survey Prof. Paper 78, p. 87, 1913. Calkins, F. C., and Emmons, W. H., U. S. Geol. Survey Geol. Atlas, Philipsburg folio (No. 196), p. 12, 1915.

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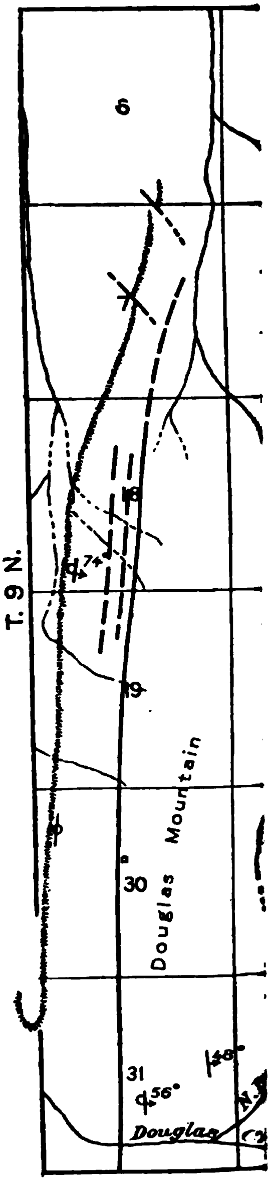

RECONNAISSANCE GE

The sedimentary beds adjoining the sills have been changed to tough and flinty rocks that commonly weather to rusty shades, but the metamorphism does not extend far from the contact. The rocks in the vicinity of the Wasa mine also show a moderate degree of contact metamorphism, the Kootenai shales having lost their characteristic purple shades and the limestone being partly changed to hornstone. No igneous rocks are known within a mile of this locality, but the metamorphism plainly indicates that an intrusive granitic rock is present not far below the surface.

The sedimentary beds and the sills are folded together into a sharp-crested anticline that plunges steeply northward. At the south end the axis of this fold lies along Dunkleberg Ridge, passing through the Wasa mine, but north of that point it turns eastward into the basin of Dunkleberg Creek. Dips of 60° to 80° occur on both flanks of the anticline, and the axial plane leans slightly to the west. Large synclines appear on both sides of the anticline, the one on the east being very broad and deep. A N. 20° W. fault accompanied by a thick breccia is shown in the Wasa mine workings, and about 2 miles to the west there are several other faults that are persistent, strike about north, and have caused extensive displacements.

ORE DEPOSITS.

Lodes containing lead, zinc, silver, and other metals are fairly numerous along Dunkleberg Ridge from the head of the north prong of Douglas Creek northward for 4 or 5 miles and are found also on the slope east of Dunkleberg Creek. Except the Wasa, which is a contact-metamorphic deposit, they are simple quartz veins in fissures that follow inclined bedding planes or cut across the sedimentary rocks and the diorite sills. As a rule, the veins are narrow, but in places they widen to flat lenslike bodies 3 or 4 feet thick and of considerable length and depth. Silver-bearing galena and lead carbonate derived from it are the most valuable ore minerals, although zinc blende is commonly present and in the lower workings of the Hatta mine is so abundant that the ore could not have been profitably marketed under the conditions existing 15 or 20 years ago. Generally there is abundant pyrite and a little chalcopyrite in the lower levels and corresponding amounts of limonite and copper stain above the limit of oxidation, but little direct information concerning the amount of oxidation is available. That in places the oxidized zone extends to considerable depths is suggested by the abundance of limonite in the dumps at some of the more extensive workings, but here and there galena and other sulphides were observed very near the surface. The ore shipped is reported to have contained on the average about 40 per cent of lead and 40 ounces or more of silver to the ton. Except in ore from the Hatta and Wasa mines, the percentage of zinc is generally low.

The Wasa lode is formed in the lower shaly limestone beds of the Kootenai formation, which were broken by the folding of the anticline described above. The limestone is recrystallized and partly replaced by quartz, feldspar, hornblende, and the sulphide minerals—pyrite, pyrrhotite, and zinc blende. Of these minerals the zinc blende came in last, as is clearly shown by its occurrence in a network of minute fractures that cut the other minerals. Small amounts of galena and chalcopyrite are also found in the lode.

So far as the development workings show, the ore body is very irregular in form but is at least several hundred feet long and at one place 40 or 50 feet wide and 140 feet deep. Certain shale beds appear to mark the upper limit of the ore, and a fault cuts it off below. Its lateral boundaries are indefinite, owing to numerous small post mineral slips and faults and to the fact that there is a gradual transition between the ore and the country rock. As determined chiefly by drill samples, large portions of this body are said to average 10 per cent or more in zinc. Where the lode is cut by Douglas Creek it is oxidized and much of its zinc is leached out.

The lodes in the Dunkelberg district are clearly later than the folding, which involved late Cretaceous rocks and their included diorite sills, and the mineralogy is characteristic of deposits formed by hot solutions ascending from intrusive granitic rocks. The distribution of the minerals and the metamorphism of the sediments indicate that the Wasa deposit is very near and the others moderately far from the source. A few miles south of the Dunkleberg district, in the basin of Gold Creek and elsewhere, Tertiary granodiorites are exposed and the Dunkleberg intrusion is probably of similar age and character. As a rule, no very large ore bodies are to be expected in the narrow veins, but some of them can doubtless be reopened profitably, especially should the metals maintain the average high prices of 1917.

Whether or not the Wasa lode will prove to be profitable can hardly be said to be demonstrated, but there is no doubt that it contains a very large body of low-grade zinc ore.

MINES AND PROSPECTS.

WASA.

The Wasa mine is on Dunkleberg Ridge near the head of the north branch of Douglas Creek, at an elevation of about 6,700 feet. From Hall (elevation 4,223 feet), a town on the Philipsburg branch of the Northern Pacific Railway, the mine is reached by a good wagon road

11 miles long that goes up Limestone Ridge, a spur west of Barnes Creek.

In addition to several hundred feet of diamond-drill holes, the principal workings consist of four adit levels that are driven eastward in a steep southwest slope and aggregate about 1,500 feet in length. Three of the adits, known as No. 1 and No. 2 tunnels and the Simmer Jack or No. 3 tunnel, are near together, and the fourth, or Kirkendall tunnel, is about 1,000 feet to the southeast and considerably higher. The country rock is chiefly thin-bedded fine-grained limestone that has been partly altered to a light-gray or buff compact hornstone. Under the microscope specimens of the most common variety of the rock show a fine mosaic of calcite and quartz in which are a few grains of secondary hornblende. A dull-greenish rock that is found close to the ore bodies shows very coarse calcite cleavages, the crystals being penetrated by irregular veinlets of secondary plagioclase, quartz, and chlorite. Grains and specks of pyrite are disseminated rather sparingly through both varieties of the rock, and near the lode pyrrhotite and zinc blende also occur. The lode is formed in a squeezed and broken zone along the axis of a northerly anticline, pyrite, pyrrhotite, and zinc blende having been introduced, replacing the rock and forming ore bodies of irregular shape and rather indefinite limits. Tunnels Nos. 1, 2, and 3, together with the drill holes, indicate the existence of a thick tabular ore body 600 feet long that trends nearly north. One drill hole near the middle of the explored area goes through 140 feet of ore; others from 20 to 80 feet. The ore is from 30 to 50 feet wide in the tunnels, but its boundaries are uncertain and irregular, partly because of many small slips and faults and partly because the mineralization gradually fades out.

In tunnels Nos. 1, 2, and 3 the ore is cut off below by a fault which strikes N. 15° W. and dips about 45° E., and whose projection also coincides with the lower limit of the ore in the drill holes. In tunnel No. 1 the fault is accompanied by 50 or 60 feet of breccia composed of country rock and oxidized lode matter. A large amount of similar breccia is shown in tunnels Nos. 2 and 3, and some other workings about 500 feet farther south along the strike of the fault have also penetrated much soft crushed material. Presumably the dislocation has been extensive and the movement normal. Owing to the absence of satisfactory exposures, the fault could not be traced along the surface in the vicinity of the mine, but it probably can be found if careful examinations are made farther north and south. Two miles west of the Wasa mine similar strike faults persist for several miles along the Douglas Mountain anticline and cause normal displacements of as much as 1,000 feet.

The ore normally is a hard, flinty rock derived from shaly limestone by replacement with silica, the process having begun along many insignificant fractures and spread outward until the whole mass was altered. Pyrrhotite, pyrite, and locally chalcopyrite accompanied the silica and were followed by zinc blende, which forms a network of veinlets that partly replace the other sulphides. In addition small quantities of galena and siderite are scattered here and there through the lode.

The lower limit of oxidation is irregular as a rule, but it is not more than 50 feet below the surface. Owing to a loose and open texture, the fault breccia is thoroughly oxidized at the tunnel levels, where it shows crusts of a pale yellowish-gray or white earthy material that contains zinc and is probably in part smithsonite.

The breccia is regarded as ore by the owners, but it appears to be of a very low grade. The main ore body is evidently rich in places, and average samples of it are said to assay from 2 to 15 per cent of zinc. An ore body 1,000 feet farther south and apparently separate from the one described is said to have been penetrated by the Kirkendall tunnel. Specimens from it show abundant pyrite and tetrahedrite cut by zinc blende.

SUNSET.

The Sunset claim is on the slope east of Dunkleberg Creek, near the stream level and about 2½ miles north of the Wasa mine. An adit level 100 feet long penetrates a diorite or gabbro sill and follows a narrow vein that strikes N. 75° E. and dips 45° N. The vein filling consists of soft, earthy, ocherous material in which bunches of quartz and partly unoxidized galena occur. There is also a little chalcopyrite. At the time of visit preparations were being made to ship this ore, which, in addition to some lead, is said to carry 30 or 40 ounces of silver to the ton.

PEARL.

On the Pearl claim, half a mile north of the Wasa mine, are the ruins of a small blast furnace in which a small amount of lead ore is said to have been smelted. An incline, now caved, has been sunk on a vein a foot or two wide that occupies a bedding plane in Colorado shale striking N. 20° E. and dipping 50° W. Ore scattered about consists of quartz and limonite showing some galena and a little copper stain.

SUMMIT.

Half a mile north of the Pearl two short adits on the Summit claim expose a vein on a bedding plane in sandstone of the Colorado formation that strikes northeast and dips steeply northwest. The vein, ordinarily narrow, is widened in places to flat lenslike bodies as much as 4 feet thick, composed chiefly of quartz, pyrite, limonite, and galena. The production of five carloads of ore containing 40 per cent of lead and 60 ounces of silver to the ton is reported.

FOREST ROSE.

The Forest Rose mine, said to have produced about $100,000 worth of silver-lead ore, is a mile north of the Wasa and on the steep slope west of Dunkleberg Creek at an elevation of about 5,500 feet. Several workings have been made on a vein that strikes northeast and dips about 45° NW., in part following a bedding plane and in part cutting across a bed of Kootenai gastropod-bearing limestone. The size of the dumps indicates rather extensive underground workings, of which only the superficial portions were accessible for examination in 1916. Near the surface the vein is generally not much more than a foot in width and consists of quartz, limonite, and a little galena and pyrite. The dumps contain much iron-stained "honeycomb" quartz. Specimens of unoxidized ore contain abundant pyrite and galena and a very little chalcopyrite. Steps to reopen this mine were reported to be under consideration early in 1917.

HATTA.

The Hatta mine is in an area of diorite or gabbro near the top of the slope east of Dunkleberg Creek, about 2 miles northeast of the Forest Rose. A rather large production of silver-lead ore is reported, but operations were suspended several years ago because zinc blende became too abundant for the ore to be profitably mined at that time.

JACKSON.

The Jackson mine is half a mile south of the Hatta and similarly situated with respect to the topography and geology. A production several years ago of $25,000 in silver and lead is reported. Only the superficial parts of the workings, which, to judge from the dumps, are fairly extensive, were accessible for examination in 1916. The vein is a fissure in diorite or gabbro, strikes N. 20° W., dips 35° E., and is from 1 to 3 feet wide. The ore is composed of lead carbonate and limonite, which partly fill the cavities in a fine skeleton or honeycomb quartz. No unoxidized ore was seen.

THE ANTIMONIAL SILVER-LEAD VEINS OF THE ARABIA DISTRICT, NEVADA.

By Adolph Knopf.

INTRODUCTION.

The Arabia district, in Humboldt County, Nev., is an old mining camp which, long idle after its first period of activity in the late sixties, has again become active under the stimulus of the present high prices of lead, antimony, and silver. The first smelter erected in Nevada, at Oreana, on the Southern Pacific Railroad, was built in 1865 to reduce the ore of the Montezuma, the principal mine in the Arabia district. The ores of the district are notable in that they consist almost wholly of silver-bearing bindheimite, the so-called hydrous antimonate of lead.

The Arabia district is in the foothills of the Trinity Range, about 4 miles west of Oreana (Nenzel railroad station). The elevation of the district at the Montezuma mine is 4,600 feet—about 400 feet above Oreana. The topography is open, the hills are low and rounded, and the relief is from 200 to 300 feet. The district is wholly without water.

GENERAL GEOLOGY.

Granodiorite prevails throughout the district. Scattered through the granodiorite, however, are blocks and irregular masses of thoroughly contact-metamorphosed sedimentary rocks of the hornfels type. The granodiorite and hornfels are cut by numerous veins carrying bindheimite and quartz. Rhyolite, far younger in age than the ore deposits, in places caps the granodiorite and the inclosed masses of hornfels.

The granodiorite is a fine-grained, evenly granular rock consisting of feldspar, quartz, and biotite. It is as a rule thoroughly altered to a white granular rock resembling an aplite. Under the microscope this alteration is found to be due to conversion of the feldspar and biotite into sericite. As a result of this sericitization the quartz, which is inconspicuous in the better-preserved rock, has become prominent and emphasizes the aplitic appearance of the altered granodiorite. The alteration is so widespread throughout the district that no fresh material was found, and in consequence there is some doubt as to whether the rock is a granodiorite or the closely allied species quartz diorite.

The sedimentary rocks embedded in the granodiorite are chiefly metamorphosed shales. In places they show bedding. They are homogeneous, uniform rocks and contain no strata that are readily and certainly distinguishable from the rest. They are grayish black and extremely fine grained, ranging from microcrystalline to aphanitic, and under the microscope are found to consist mainly of an intimate intergrowth of quartz and biotite. The biotite makes up about one-third of the bulk, and the remainder is quartz, except for a subordinate amount of white mica. Rock of this kind is typical hornfels. The metamorphosed sediments northwest of the Montezuma mine differ from those just described, resembling faintly mottled cherts. Their high specific gravity, however, indicates that they are not cherts, and under the microscope they are seen to consist of quartz and finely granular pyroxene.

The blocks of hornfels occur not only at the surface but also rather unexpectedly in places underground—for example, where the surface exposures, consisting wholly of granodiorite, would lead one to expect only granodiorite in depth. It is clear that some of the blocks are wholly surrounded by granodiorite. The rocks are cut by dikes of granodiorite, which, so far as observed, range from an inch to 15 feet in thickness. The occurrence and distribution of these masses of contact-metamorphosed rocks show that erosion has cut down some distance below the irregular roof of an intrusive mass of granodiorite.

The age of the contact-metamorphic sediments is not certainly known, as no fossils were found in them. According to Arnold Hague[1] the only sedimentary rocks found in the Trinity Range are Jurassic slates, the Triassic rocks so common in the Humboldt Range, the next range to the east, being entirely absent. It is possible, therefore, that the metamorphosed sediments in the Arabia district are Jurassic, and that the granodiorite which intrudes them, instead of being of Archean age, as Hague thought, is early Cretaceous, its age conforming with what has been established in recent years for similar intrusions in other parts of Nevada.

The rhyolites resting on the granodiorite are gray, brown, and black varieties, which as a rule are conspicuously flow-streaked and in places are so thinly flow-laminated as to resemble shales. They contain porphyritic crystals of feldspar and of biotite in lustrous plates. Under the microscope the feldspar phenocrysts prove to be andesine, embedded in a glassy groundmass, and tridymite is found to occur in some abundance in the pores of the rock. The absence of sanidine and quartz phenocrysts and the prevalence of andesine point to latitic affinities of the rhyolites. Black obsidian occurs in places at the base of the rhyolite lavas, but it is nowhere more than a few feet thick.

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[1] Hague, Arnold, Descriptive geology: U. S. Geol. Expl. 40th Par. Rept., vol. 2, p. 753, 1877.

The rhyolites are probably of Miocene or Pliocene age.

THE VEINS.

The ore bodies are fissure veins in granodiorite and hornfels. Those in granodiorite are inclosed between well-defined walls, but within a short distance after entering the hornfels they fray out into narrow stringers. Some of the veins are traceable on the surface for more than 1,000 feet.

The principal ore mineral is argentiferous bindheimite, the so-called hydrous antimonate of lead. In the richer ore bodies it fills the veins from wall to wall in solid masses; in the leaner ore bodies considerable coarse milk-white quartz is associated with it. Under the microscope the quartz from the Montezuma mine is found to inclose numerous small prisms of tourmaline.

The bindheimite occurs in a variety of forms, but two of these are particularly characteristic of the district. One of them is a deep yellowish-brown amorphous variety of high, brilliant pitchy luster, and the other is a yellow compact earthy variety that has commonly a divergent columnar structure, and is obviously pseudomorphic after the sulphide from which the bindheimite is derived. Small particles of this sulphide are occasionally found in the bindheimite and prove to be fibrous jamesonite. The following analysis of bindheimite from the Montezuma mine is given by J. D. Hague:[1]

Analysis of bindheimite from the Montezuma mine, Nev.

[W. G. Mixter, analyst.]

Sb_2O_5	51.94
PbO	40.89
Ag	.33
Fe_2O_3	.60
Insoluble residue	1.66
Water	4.58
	100.00

The different varieties of bindheimite are irregularly commingled throughout the ore. The brown, highly pitchy variety is generally surrounded by a delicate banding, which consists of an alternation of the brown and yellow varieties. Bindheimite, as first pointed out by Cornu,[1] is a mineral gel,[2] and this banding appears obviously to be the result of the rhythmic precipitation of some diffusing compound before the bindheimite gel had set (the Liesegang effect). The diffusing compound was probably an iron salt, and its rhythmic precipitation was due to hydrolysis, a possibility that was shown experimentally by Liesegang.[3]

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[1] Hague, J. D., Mining industry: U. S. Geol. Expl. 40th Par. Rept., vol. 3, p. 299, 1870.

Under the microscope the pitchy bindheimite is seen to be a deep yellowish-brown translucent homogeneous substance. A highly birefringent mineral, possibly valentinite (Sb_2O_3), is intergrown with some of the bindheimite from the Montezuma mine.

Other oxidized minerals, which so far as now known occur only in the ore of the Montezuma mine, are plumbojarosite (basic sulphate of lead and ferric iron), scorodite, cerusite, and gypsum.

The ore of the Montezuma mine contained about 50 per cent of lead and antimony and 80 ounces of silver to the ton.[4] The ore left in the stopes of the Electric and Jersey mines contains about 10 per cent of lead, 10 per cent of antimony, and 15 ounces of silver and 0.10 ounce of gold to the ton.

MONTEZUMA MINE.

The Montezuma has been the chief productive mine in the district. In 1868 Raymond[5] estimated that it had produced 1,500 tons of ore and that the reserves in sight were 1,200 tons. To treat the ore of this mine the company built the smelter at Oreana, on Humboldt River, after earlier unsuccessful attempts had been made to reduce the ore in a stamp mill. At first only the silver was recovered during smelting, the antimony being sublimed and the lead cupeled. On the completion of the Central Pacific Railway, however, transportation costs were so much lowered that the lead and antimony could be profitably marketed, and the crude metal from the shaft furnace, an alloy of lead and antimony, was sold without further treatment to Selby & Co., of San Francisco, who paid $100 a ton for the base metal and $1 an ounce for the silver it contained. The ore from the mine carried from 40 to 50 per cent of lead and antimony and from 60 to 80 ounces of silver to the ton. In the spring of 1917 the old slags from the Oreana smelter were being shipped to the smelter at Midvale, Utah, to recover the lead, antimony, and silver in them. They averaged 7 per cent of lead, 5 per cent of antimony, and 2 ounces of silver to the ton. This accords with Hague's statement that the slags were poor, the richer slags having been returned to the furnaces. The smelting works and methods of treatment are described in detail by Hague.[1] During the removal and shipment of the old slags in 1917 some of the tailings from the unsuccessful stamp mill were uncovered; they carry 18 per cent of antimony, 24.7 per cent of lead, and 17 ounces of silver to the ton.

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[1] Cornu, F., Ueber die Verbreitung gelartiger Körper im Mineralreich, ihre chemisch-geologische Bedeutung und ihre systematische Stellung: Centralbl. Mineralogie, Jahrg. 1909, p. 330.

[2] As a colloid mineral bindheimite can not be given a definite chemical formula, such as is denoted by the term hydrous antimonate of lead. Lacroix, in fact, writes $y\text{PbO}.x\text{Sb}_2\text{O}_5.z\text{H}_2\text{O}$.

[3] Liesegang, R. E., Geologische Diffusionen, p. 147, 1913.

[4] Raymond, R. W., Mineral resources of the States and Territories west of the Rocky Mountains for 1868, pp. 130-131, 1869.

[5] Idem, p. 129.

The principal workings of the Montezuma mine consist of a large pit 90 feet long and 20 feet wide, whose floor is about 20 feet below the surface of the hill. In early days an incline was sunk 120 feet on the vein, but at 60 feet it passed out of ore. Subsequently a drift was run westward at the 60-foot level some 80 or 100 feet, and was reported as being in good ore for the whole distance.[2] At the present time the lower workings are inaccessible below a level 35 feet vertically below the floor of the pit.

The mine has been practically idle since 1875. In 1917 the old dumps were sorted for the bindheimite they contained, and some work was done toward reopening the mine, the intention being to explore it in depth.

The ore body occupies a fissure in the granodiorite; it trends east and dips 45° N. The walls are well defined and are strongly marked with groovings that dip westward at a moderate angle. The ore body formerly worked appears to have been a large lens that pitched westward, possibly in conformity with the groovings scored on the footwall. The footwall is in part a large block of metamorphic shale inclosed in the granodiorite. A crosscut that was driven through the shale shows that the shale is cut by a close network of quartz veins, so that the larger proportion of exposed rock consists of coarse-grained white quartz, which locally carries exceedingly coarse crystalline calcite.

The main ore body, at the level of the pit, was 14 feet thick and 90 feet long. The vein was "filled with ore, variable in quality but almost entirely free from gangue, and nearly all fit to send to the furnace without assortment." [3] Below the level of the pit the vein averages 6 feet in thickness. The ore formerly worked consisted, as the old records show, largely of bindheimite, containing traces of residual jamesonite. Cerusite, black manganiferous oxide of antimony, gypsum, and arsenopyrite partly oxidized to the green mineral scorodite can still be found locally. In the workings now accessible below the floor of the pit the vein filling consists of secondary "jasper" irregularly banded and mottled in yellow and red. Microscopic examination, supported by chemical tests, shows that the yellowish jasper contains considerable plumbojarosite in closely packed aggregates of hexagonal tablets. The plumbojarosite not uncommonly occurs in perfectly formed crystals as a replacement of coarse quartz grains that are residual from the primary ore and are now inclosed in the secondary cryptocrystalline quartz forming the bulk of the jasper.

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[1] Hague, J. D., Mining industry: U. S. Geol. Expl. 40th Par. Rept., vol. 3, pp. 300-308, 1870.

[2] Idem, p. 299.

[3] Idem, p. 298.

OTHER MINES AND PROSPECTS.

Considerable work was done in early days on the other veins of the district. These are narrow veins, considerably smaller than the Montezuma, and trend north and dip 30° – 60° E. The most development work has been done on the Electric and Jersey veins, which are 1,000 feet north of the Montezuma mine.

The Electric vein is opened by an incline 350 feet long, from which four levels have been turned off. A vertical depth of 210 feet is attained. The vein has been stoped, but about 1,000 tons of antimonial lead-silver ore is estimated to remain in the stopes. The vein ranges in thickness from 1 to 3 feet. On the upper levels it is inclosed in granodiorite and lies between remarkably even, regular walls, but in the hornfels, which it enters in the lower part of the mine, it splits up into thin barren stringers that almost pinch out. On the surface the Electric vein enters hornfels 60 feet south of the incline and abruptly narrows down. A formidable-looking postmineral fault, trending east and dipping 45° N., has been cut in the lower workings, but as it fails to displace the contact of the granodiorite and hornfels 400 feet east of the vein, it can not displace the vein more than a few feet at most.

The Jersey vein is 220 feet east of the Electric vein, to which it is roughly parallel. It is separately owned, being held by a claim, 10 feet wide and 1,200 feet long, which is wholly inclosed in the Electric claim. It is opened by a number of inclines, the main one of which is 150 feet long and reaches a depth of 71 feet. The upper levels are in granodiorite, but in depth the vein enters the hornfels, with results unfavorable to the quality and quantity of ore. A notable feature is a conspicuous postmineral fault, which despite its appearance suggestive of strong movement dislocates the vein not more than a few feet. South of the fault the most massive bindheimite ore left in the mine was seen; it occurs in bodies as much as 1 foot in diameter consisting solidly of the pitchy variety.

The Electric and Jersey veins show clearly, both along the strike and down the dip, that the hornfels has been highly unfavorable for vein formation. In both mines, however, there remains much territory in granodiorite which is probably worthy of exploration.

At depths greater than have yet been obtained the veins will be found to reenter the granodiorite and probably lose their stringered character, becoming simple fissure fillings. The depth at which this change will be reached can not be predicted, but it is probably not great and may be as little as a few feet.

There are numerous other narrow veins in the district that are of the same general character as the Electric and Jersey veins; they are on patented claims owned by the Electric Mining & Reduction Co.

The Aztec is a recent location in which the mineralization occurred along a fissure that is possibly the westward extension of the fissure on which the Montezuma ore body is situated. The vein is 6 inches thick and dips 60° N.; the hanging wall is sedimentary rock and the footwall is granodiorite. It carries bindheimite, which is pseudomorphic after jamesonite, and quartz inclosing a little chalcopyrite.

PERSISTENCE OF ORE IN DEPTH.

The main questions of practical interest with reference to the veins of the district are the probable tenor of the ore in the sulphide zone and the persistence of the ore in depth. Sulphides are rare in the ore bodies so far laid open to view, and it is probable that this highly oxidized ore may persist to depths of 400 or 500 feet, or down to the level of Humboldt River.

Because lead and antimony do not readily go into solution during the oxidation of their sulphides, it is probable that the primary sulphide ore will contain essentially as much lead and antimony as the oxidized ore. During oxidation, however, much sulphur was eliminated, doubtless in the form of sulphuric acid, and this process favored downward migration of the silver. The silver taken into solution in the zone of oxidation would be precipitated by the primary sulphides that occur at greater depth, and it is therefore not unreasonable to expect that rich secondary antimonial silver sulphides will be found just above the zone of primary sulphides.

Jamesonite, so far as its paragenesis is known, appears to occur more commonly in ore deposits formed at high temperatures, as is indicated, for example, by its occurrence as the principal ore mineral in the contact-metamorphic deposit at Zimapan, Mexico,[1] and in tin-bearing veins in Bolivia. The tourmaline content of the quartz in the Montezuma vein accords with this supposition. If, then, the veins of the Arabia district were formed under conditions of high temperature, this feature, considered together with the widespread, thorough hydrothermal alteration of the granodiorite inclosing the veins of the district, indicates that some of the stronger veins may carry ore in depth. This possibility, combined with the chance that a zone of enriched silver sulphides exists in depth, suggests that the district merits deeper exploration than has yet been attempted.

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[1] Lindgren, Waldemar, and Whitehead, W. L., A deposit of jamesonite near Zimapan, Mexico: Econ. Geology, vol. 9, pp. 435-462, 1914.

STRONTIANITE DEPOSITS NEAR BARSTOW, CALIFORNIA.

By Adolph Knopf.

LOCATION AND DISCOVERY.

Strontianite in economically important quantity has recently been found near Barstow, San Bernardino County, Cal. The deposits occur 10 miles north of the town, in a group of hills known locally as the Mud Hills, because occasional desert storms convert the clay beds, of which the hills are largely composed, to masses of mud, but this designation is likely to be supplanted by the name Strontium Hills. The deposits lie at altitudes between 3,000 and 4,000 feet and are readily accessible over fairly good roads, the grade of which is mainly downhill to Barstow.

The strontianite was discovered by Henry Hart and T. G. Nicklin, who were prospecting for borax. In 1915 they found masses of a fibrous mineral of resinous color and luster, which they thought might be either "needle borax" or "rosin jack" (zinc blende). At Barstow the mineral was provisionally determined as witherite (barium carbonate), but later, doubts being felt as to the validity of the determination, specimens were sent to Prof. Charles Palache, of Harvard University, who established the identity of the mineral as strontianite (strontium carbonate).

The first claims for strontianite, known as the Needles group, were staked in October, 1916, and since then nearly 40 claims have been located. The whole area in which strontianite occurs had been staked for oil during the boom that culminated in 1913, and the oil claims had been marked by monuments, some of which were built partly of solid lumps of strontianite.

The strontianite deposits were briefly examined by me in February, 1917, and it gives me pleasure to acknowledge my indebtedness to Messrs. L. G. Henderson, T. G. Nicklin, and A. A. Turner for facilitating the examination.

GENERAL GEOLOGY.

The Strontium Hills are underlain by a series of lake and terrestrial deposits which have been folded into a syncline. (See Pl. XI.)

These beds have been partly described by Baker[1] under the name "Rosamond series," and later more fully by Pack.[2]

The syncline into which the beds have been bent is referred to by Baker and Pack as the Barstow syncline. A monograph on the fauna of the beds is in preparation by Prof. J. C. Merriam,[3] who discusses also the age and correlation of the beds. The term "Barstow formation" is used by Merriam for the deposits containing the upper Miocene fauna and comprising the uppermost beds of the Barstow syncline, but it is recognized that this fauna may occur in all of the strata of the syncline.[4] The fauna includes about 30 species, among which horses of at least four species and camels are most abundantly represented, for it is the bones of these animals that are usually found.[5]

A threefold subdivision of the beds in the Strontium Hills may easily be recognized, as Pack has pointed out. The lowest member consists largely of granitic detritus, remarkably fresh in composition and consisting of angular boulders, some of which are as much as 5 feet in diameter. It is without more than a trace of bedding and is clearly an ancient alluvial deposit, a "fanglomerate." Some rhyolite tuff occurs with it.

The middle subdivision, which contains the strontium, is made up chiefly of grayish-green clay in thick beds. The erosion of the clay beds has produced a badland topography which is highly characteristic of the middle member of the Barstow syncline. At the surface the clay is loosely coherent, but in places it grades into shale, which is fairly well bedded. Crystals of gypsum half an inch or so in diameter are common throughout the clay beds. Moreover, the clay yields calcium sulphate on extraction with water, and it effervesces freely in hydrochloric acid; it is therefore a gypsiferous, calcareous clay. Calcareous concretions of odd and peculiar patterns are of widespread occurrence in the clay beds; they are locally called "fossils."

Above the clays come more highly indurated beds, consisting of calcareous tuffs, white rhyolite tuff, sandstone, and limestone in persistent beds 4 to 6 feet thick. Many of these limestones are clearly of algal origin, as shown by the concentric circular patterns on their weathered surfaces. Some of the limestones have an apparently brecciated structure—that is, they carry angular fragments of limestone embedded in a dense matrix of somewhat different color. However, as there are all gradations between such seemingly brecciated

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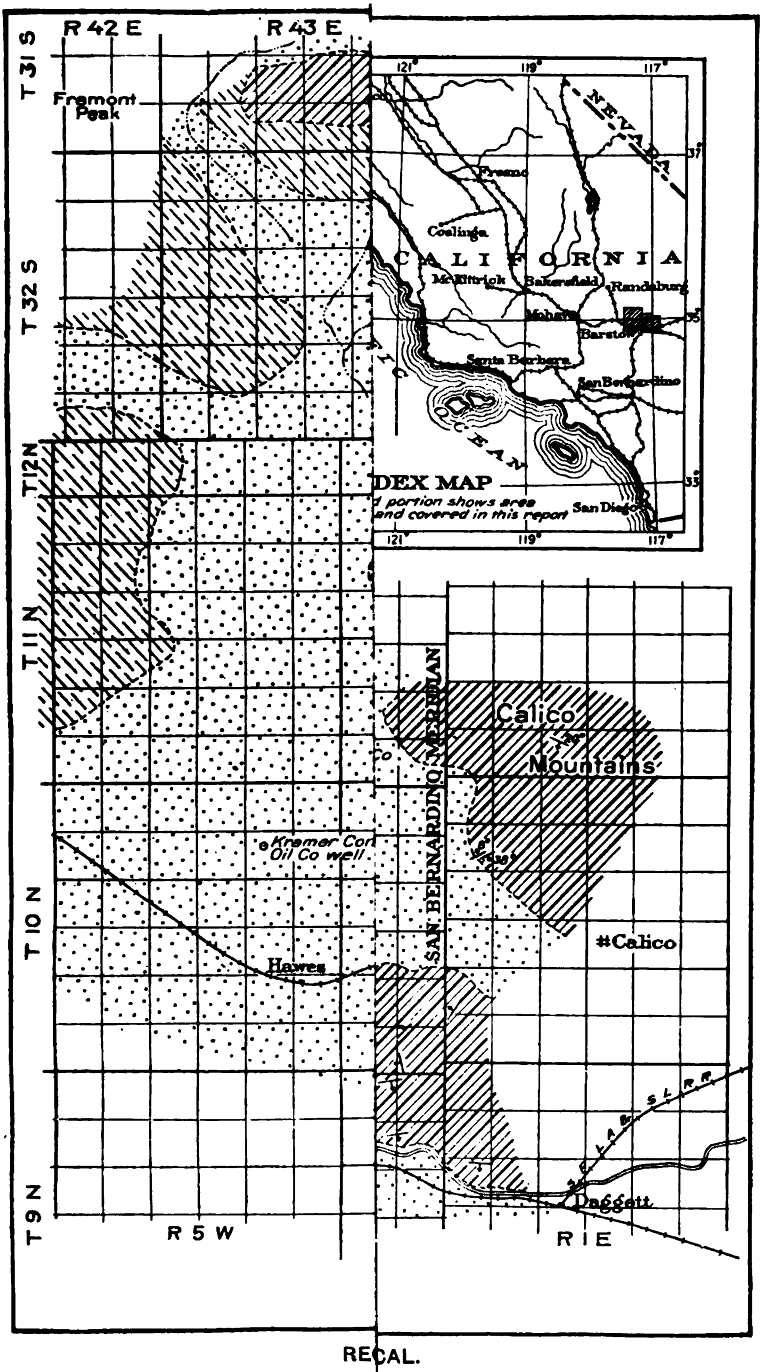
[1] Baker, C. A., Notes on the later Cenozoic history of the Mohave Desert region in southeastern California: California Univ. Dept. Geology Bull., vol. 6, pp. 342–347, 1911.

[2] Pack, R. W., Reconnaissance of the Barstow-Kramer region, Cal.: U. S. Geol. Survey Bull. 541, pp. 141–151, 1913.

[3] Oral communication.

[4] Merriam, J. C., unpublished MS.

Merriam, J. C., Extinct faunas of the Mohave Desert, their significance in a study of rigin and evolution of life in America: Pop. Sci. Monthly, vol. 86, p. 255, 1915.


R 42 E
R 43 E
T 31 S
Fremont Peak
T 32 S
T 12 N
T 11 N
T 10 N
T 9 N
R 5 W
R 1 E
SAN BERNARDINO MERIDIAN
Calico Mountains
Calico
Kramer Con Oil Co well
Hawes
Daggett
A. T. & S. F. R. R.
Co
121°
119°
117°
37°
35°
33°
NEVADA
CALIFORNIA
Fresno
Coalinga
McKittrick
Bakersfield
Randsburg
Mohave
Barstow
Santa Barbara
San Bernardino
San Diego
PACIFIC OCEAN
DEX MAP
d portion shows area
and covered in this report

RECAL.

limestone and that in which the algæ are preserved unbroken, it is probable that the brecciation is an original structure—that is, that the angular fragments are broken algal growths which were incorporated in the limestone at the time the limestone was formed.

A large specimen of the best-preserved algal limestone was forwarded to Dr. Charles D. Walcott, who reports as follows:

> I had the specimen cut through vertically, also three thin sections made of a portion of it. The microscopic section shows essentially the same general structure that occurs in recent fresh-water calcareous algal deposits, and they are also very similar to deposits that occur in the supposed fresh-water beds in the Algonkian Belt limestones of Montana.
>
> The thin sections show the same type of lamination and structure as the thin sections of the similar forms from the Algonkian and the Cambrian limestones. From the character of the limestone I do not think it is probable that the algal cells will be found, but from the general resemblance of the structure in the specimen received from Mr. Knopf, it is exceedingly probable that the lime in the specimen was deposited through the agency of the blue-green alga.

The section described in the preceding paragraphs is that near the east end of the Barstow syncline, near the discovery group of claims, where only the north limb of the syncline is exposed. Farther west the strontium deposits occur in the south limb of the syncline. The beds here resemble those of the middle subdivision already described, but the interbedded algal limestones are especially conspicuous. They weather out in relief, forming ledges 300 to 400 feet long. Their greatest thickness is 6 feet, and they gradually pinch out along the strike. As seen from a distance the ledges roughly resemble aggregates of cauliflower heads. Branching, arborescent forms also occur, in which the separate branches are about 3 inches in diameter.

STRONTIANITE DEPOSITS.

Strontianite and strontium-bearing rock have been found at a large number of places in a belt about 2 miles long. They occur as layers that lie parallel to the bedding of the inclosing clays and are distributed at intervals through a thickness of several hundred feet.

The strontianite occurs in two forms—as fibrous masses of resinous color and luster (locally spoken of as "rosin strontianite") and as dense, exceedingly fine grained (aphanitic) gray or drab material, which resembles limestone. The fibrous variety, because of its weight and evident purity, is obviously of high grade; the grade of the aphanitic variety, of course, can not be determined without chemical examination, except very roughly by its high specific gravity. The two varieties occur separately, as a rule, but in some deposits they are intermingled, spherulites of coarse resinous strontianite being irregularly scattered through aphanitic gray strontianite rock.

The thickest body of pure spherulitic strontianite that had been found at the time of visit is 14 inches thick; this body is lenticular and pinches out within a few feet along the strike, but other bodies of strontianite appear farther along at the same stratigraphic level.

The gray aphanitic strontianite occurs in layers as much as 3 feet thick. In all respects these layers simulate ordinary beds of limestone interstratified with the predominant clays, and it is only after the supposed limestone has been handled that its abnormal character is suspected. Some of the gray strontianite rock contains angular glassy particles of feldspar and quartz and more rarely small fragments of brown vitrophyre. Under the microscope the gray strontianite rock is found to consist almost wholly of minute spherulites of strontianite, the different spherulites interfering and forming a mosaic of polygonal grains.

The general dip of the strontianite deposits in the discovery claims is 10°–30° S. In places, however, the beds are faulted and for short distances lie horizontal or even dip to the north.

Strontianite rock obtained near the main workings on the Needles group was analyzed in the laboratory of the Geological Survey. It is a faintly banded, aphanitic rock resembling a drab limestone; under the microscope it is seen to be composed chiefly of extremely small obscure spherulites of strontianite.

Partial analysis of strontianite rock from the Strontium Hills, Cal.

[R. C. Wells, analyst.]

SrO	55.20
CaO	5.19
BaO	None.
CO_2	28.18
SO_3	.28
SiO_2	5.59
Al_2O_3	1.17

Computation of the analysis shows that the strontianite rock contains 78.6 per cent of strontium carbonate. The ratio of strontia to lime is approximately the same as in the pure, coarsely crystallized strontianite whose analysis is given on page 262, where it is pointed out that the lime, as calcium carbonate, is an isomorphous constituent of the strontianite. Using the composition of the strontianite there given, computation of the analysis shows that the strontianite rock consists of 87.8 per cent of strontianite.

In the western part of the district the geologic features differ somewhat from those already described. The strontium-bearing beds occur on the south limb of the Barstow syncline and dip 70° N. They consist largely of brownish calcite, with subordinate celestite and less strontianite. They are consequently of low grade, and none of the material shown to me has proved on laboratory examination to be of commercial value. An analysis of supposedly high-grade material from the ledge known as the Upper Brown was made in the laboratory of the Geological Survey; the preliminary microscopic examination showed it to be composed of calcite, celestite, and strontianite.

Partial analysis of strontium-bearing rock from the Strontium Hills, Cal.

[R. C. Wells, analyst.]

SrO	12.9
CaO	39.5

A remarkable feature of the western part of the strontium-bearing belt is the abundant occurrence of fibrous spherulitic, resinous-colored calcite exactly resembling the "rosin strontianite" found on the Needles group of claims. This calcite occurs in veinlets and as deposits formed by replacement of limestone beds. Unless supposed strontium-bearing material is subjected to quantitative chemical analysis, the presence of this deceptive calcite is certain to cause much disappointment.

The work done in opening the prospects in the strontium-bearing belt was small at the time of visit, and exposures of strontianite were, in the main, the natural outcrops. The output in 1917 was 500 tons of strontianite rock.

MINERALOGY OF THE DEPOSITS.

STRONTIANITE.

The purest strontianite, as already mentioned, occurs in compact masses of thin fibers or needles. The fibers average about 1 inch in length but exceptionally are as much as 3 inches long. They radiate from centers, thus forming either fan-shaped aggregates or completely spherical masses. In the dense aphanitic variety the strontianite, as shown by the microscope, occurs also in spherulites, which, however, are very minute and the fibers of which are not as sharply individualized as in the larger aggregates.

The mineral strontianite, as shown by over 30 analyses on material from many localities in different parts of the world, never contains 100 per cent of strontium carbonate but invariably carries some isomorphous calcium carbonate, generally from 4 to 6 per cent.[1] The strontianite from the Westphalian deposits, whose homogeneity was tested microscopically, carries from 6 to 11 per cent of isomorphous calcium carbonate.[2] In view of these facts it appeared advisable to determine the chemical composition of the strontianite from Barstow, Cal. The following partial analysis was made in the laboratory of the Geological Survey by R. C. Wells. On examination in thin section and in oils the strontianite taken for analysis was found to be homogeneous and free from inclusions or intergrowths of calcite or aragonite. The refractive indices, γ and α, as determined by the immersion method, are respectively 1.67 and 1.52. Consequently the strontianite shows the strong difference in relief characteristic of calcite and aragonite. The color is pale brownish yellow, the intensity of which varies strongly according to the direction in which the mineral is viewed under the microscope.

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[1] Doelter, C., Handbuch der Mineralchemie, vol. 1, pp. 481–483, 1912.

[2] Beykirch, J., Ueber den Strontianite des Münsterlandes: Neues Jahrb., Beilage Band 13, pp. 396–407, 1901.

Partial analysis of strontianite from Strontium Hills, Cal.

[R. C. Wells, analyst.]

SrO	60.99
CaO	6.40
BaO	None.
SO_3	.05
CO_2 (computed)	29.86
	97.30

Computation of the analysis shows that the strontianite consists of 87 per cent of strontium carbonate and 10.25 per cent of calcium carbonate.

As the calcium carbonate present in the strontianite is an isomorphous constituent of the mineral and not a mechanical admixture, it can not be separated and removed mechanically by vanning tables or similar means. Further, it is unlikely that strontium-bearing material carrying more than 87 per cent of strontium carbonate can be obtained; in fact, only by the most careful sorting of the "rosin strontianite" will it be possible to obtain a commercial product running as high as 87 per cent strontium carbonate.

Minerals believed to be strontianite were tested at Barstow by those prospecting the district as follows: The mineral was placed in acid, alcohol was added and ignited, and the color of the flame was noted in a darkened room. The intensity of the redness of the flame was used as a measure of the amount of strontium present in the mineral examined. This test is very unsatisfactory, inasmuch as the purest strontianite of the district, which, as the preceding analysis shows, contains 10 per cent of calcium carbonate, gives to the alcohol flame a yellowish-red color not appreciably different from that imparted by pure calcite. More reliable results can be obtained by removing, by means of a small loop in the end of a platinum wire, a bit of the solution made by dissolving strontianite in hydrochloric acid and observing the color produced when it is strongly heated in the flame of a Bunsen burner, for the strontium flame persists longer than the calcium flame. Gasoline or alcohol blast lamps made especially for field use may be purchased from chemical supply houses and are excellent substitutes for Bunsen burners. Platinum wire may also be purchased from such dealers. With such equipment, which costs very little, the flame test for strontium can be made with some degree of certainty; but examination of the flame with a hand spectroscope, which may be purchased from dealers in chemical supplies at a moderate price, is far better. After the positions of the characteristic strontium lines on the scale of the spectroscope have been determined by examining the spectrum of a known strontium salt, reliable tests for strontium can be made, and the intensity of the strontium spectrum will roughly indicate whether much or little strontium is present.

A convenient way to distinguish between strontianite and the extraordinarily similar calcite that occurs in the district is to dilute the solution obtained by dissolving the mineral in hydrochloric acid and to add sulphuric acid; a slowly forming white precipitate coming down under these conditions indicates strontium. Caution should be observed that the solution be kept sufficiently dilute, so as not to precipitate out calcium sulphate. The dilution necessary can be determined by running a control test on a known amount of calcite, and in testing unknown minerals a quantity equal to that of the calcite employed in the control test should be used. Perhaps a simpler method still is to use a solution of calcium sulphate as precipitant instead of sulphuric acid.

The strontianite in the analyzed specimen of strontium-bearing rock from the Upper Brown ledge is found under the microscope to be rather strongly pleochroic in tones of brownish yellow. In some of the crystals the coloring matter is irregularly distributed in a manner analogous to that in certain fluorites.

CALCITE.

In the western part of the strontianite belt calcite occurs as fibrous spherulitic aggregates of resinous color, resembling exactly, therefore, the "rosin strontianite." Chemical examination shows, however, that the mineral contains no strontium, and the determination of its refractive indices proves it to be calcite. Because of its remarkably close resemblance to strontianite many claims have been located on this supposed strontianite rock.

Calcite occurs also in the western part of the belt in flat masses 1 inch thick, which have a cross-fiber structure, resembling flat slabs of wood cut at right angles to the grain. These flat slabs of calcite are scattered in profusion on the outcrop of a thick clay bed, and at the time of my visit they were being sacked in the belief that they were strontianite. They are noticeably lighter than strontianite, however, as a little experience in handling the high-grade strontianite rock will show, and chemical and microscopic tests prove them to be nothing but calcite.

The calcareous nodules and concretions that are common in the clays of the strontium-bearing area generally contain in their interiors crystalline aggregates of calcite, whose color is like that of the strontianite and causes it to resemble the strontianite of the district.

CELESTITE.

Celestite, strontium sulphate, occurs in the western part of the strontium belt. It was particularly noted in the strontium-bearing ledge known as the Upper Brown, a recrystallized limestone consisting largely of granular brown calcite, with minor celestite and some strontianite. Celestite occurs in the main as a microscopic constituent, but in places it forms small glassy crystalline aggregates of somewhat smoky tint.

PROBABLE ORIGIN OF THE DEPOSITS.

At first glance the appearance of the layers of gray aphanitic strontianite suggests that they are beds of strontianite that were deposited as chemical precipitates from the lake in which the gypsiferous clays were laid down and that the coarse spherulitic strontianite is only a recrystallization of the original fine-grained beds. When all the evidence is considered, however, another explanation becomes more probable.

Some thin strata of limestone are intercalated in the clay beds containing the strontianite layers, and these beds show the breccia structure that I have described as probably due to the inclosure of broken algal fragments during the deposition of the limestone. Similar breccia structure appears in the gray strontianite, the angular fragments of the breccia consisting of aggregates of more limpid strontianite than that of the matrix in which they are inclosed. These features suggest that the strontianite deposits were formed by the replacement of such algal limestone breccias. The low-grade strontium-bearing beds of the western part of the field supply convincing evidence as to the validity of this conclusion. Some of the limestone beds are traversed by ramifying systems of veinlets, which, although resembling strontianite, consist largely of calcite, together with minor celestite. The rock adjoining the veinlets and some of the limestone beds have been completely recrystallized into brownish calcite, which in places incloses celestite and strontianite. The microscope shows that the celestite, at least in part, is later than the strontianite, as it traverses radial strontianite in small veinlets. That such an alteration might easily have occurred appears extremely probable because of the prevalence of gypsum in the inclosing strata. Solutions would be likely to dissolve some of this gypsum and would then be able to convert strontianite into the sulphate, celestite.

In short, then, the strontianite deposits are believed to have been formed by the replacement of limestone beds, doubtless by cold meteoric waters. The high-grade deposits represent the most complete replacement, the aphanitic layers being fine-grained replacements and the "rosin strontianite" coarse-grained replacements.

SOURCES AND USES OF STRONTIUM.

The two commercial sources of strontium are celestite and strontianite. Celestite is by far the more common and supplies the bulk of the demand. In fact, strontianite has been mined in profitable amounts only in the Münster district in the Province of Westphalia, Prussia, but these deposits are now nearly exhausted.

Strontianite, which is the carbonate of strontium ($SrCO_3$), is the more valuable strontium mineral for two reasons: (1) It is readily soluble in acids and is therefore easily convertible into the required *strontium* compounds, or it can be converted into the oxide by simple calcination; and (2) it contains for a given weight more strontium than the same weight of celestite, which is the sulphate ($SrSO_4$). Pure strontianite, represented by the formula $SrCO_3$, contains 59.36 per cent of strontium, or 70.2 per cent of strontia (SrO), whereas pure celestite, represented by the formula $SrSO_4$, contains 47.7 per cent of strontium, or 56.42 per cent of strontia. All strontianites, however, contain a certain proportion of isomorphous calcium carbonate, as shown on page 261, and therefore none have the theoretical content of strontium; many celestites, on the other hand, closely approximate the theoretical composition. In recent years strontianite commanded in the German market about six times the price of celestite. A somewhat lower ratio appears to hold in the American market, as shown in late quotations for strontium " ore "[1]—" Crude carbonate, 83 per cent, 7 cents per pound for 200-mesh material. Crude sulphate, 90 per cent, 1 cent for lumps and 2 cents for 200-mesh."

The principal use of strontium is as strontium hydrate in the Scheibler process for the recovery of sugar from beet-sugar molasses. This process is employed in Germany, Russia, and France, but not in the United States, apparently on account of the high price of strontium hydrate. Other uses of strontium are in signal lights, such as railroad fusees, and in fireworks, the purpose of the strontium compound in these uses being to give a brilliant red color to the flame during combustion.

Large amounts of molasses are unavoidably produced during the manufacture of beet sugar. The production of this molasses is undesirable, as it contains more than half its weight in sugar, which is prevented from crystallizing out because of the presence of certain constituents. Approximately 150,000 tons of molasses of this origin was produced in the United States during the season of 1916, and about one-half of this quantity was " desugarized "—that is, the sugar was extracted in marketable form. Three processes are available for the desugarization of molasses, but in the United States only the Steffens process is employed. According to Meyer,[2] of the three processes available,

> The most effective, efficient, and economical is the strontia or Scheibler process. This depends on the reaction that occurs when an excess of strontium hydroxide is added to a dilute sugar solution at a temperature exceeding 100° C. The work is carried out in suitable boilers provided with steam coils and agitators, a 20 per cent to 25 per cent solution of the hydroxide being first heated and the molasses added in amount equal to about one-third that of the strontium solution. The liquid is then rapidly agitated, the temperature being kept above 100° C., when there occurs a granular, sandy precipitate of strontium disucrate. This is rapidly filtered and washed with a boiling 10 per cent solution of strontium hydroxide, the disucrate being insoluble in hot solutions.

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[1] Eng. and Min. Jour., vol. 104, p. 109, July 14, 1917. Quotations supplied by Foote Mineral Co., Philadelphia.

[2] Meyer, H. C., Strontium in the beet-sugar industry: Jour. Ind. Eng. Chemistry, vol. 6, pp. 1036–1037, 1914.

After the precipitate has been thoroughly washed, it is dissolved in a cold solution of hydroxide and allowed to stand for several days in crystallizing tanks. At the end of this time about 50 per cent of the hydrate separates in crystalline form and the saccharine solution is decanted and the crystalline residue centrifuged to free it from the solution. Carbon dioxide is then passed through the sugar solution, thus causing a precipitation of the balance of the strontium as the carbonate. This compound is reconverted into the hydroxide by calcining and dissolving the resultant oxide in water. The ratio of the total strontium hydroxide required for the precipitation of sugar in the beet molasses is approximately 2½ : 1. A remarkably pure sugar solution is obtained by the strontia process, so that the sugar after crystallization can be placed directly on the market without further refining.

At the present time the methods in vogue in this country are the osmosis and the lime or Steffens process. The former is rather slow and necessitates the handling of the same solution a number of times. The lime process requires special cooling apparatus, as the temperature of the sugar solution must be kept below 15° C. during the precipitation of the tricalcium sucrate, which is readily soluble at a higher temperature. There are numerous other minor objections to both of these processes, so that although the initial cost of the strontia process may be more than either of these, it can be readily seen that it is much more effective and rapid.

In connection with the regeneration of strontium hydrate, an American patent has just been issued describing a process for the rapid conversion of strontium carbonate into the oxide through the use of certain fluxes, such as fluorspar, soda ash, etc. In the past some difficulty has been experienced in treating the impure strontium carbonate precipitated from sugar solutions, owing to its being contaminated with lime, silica, and certain organic substances.

Statistics show that Germany desaccharizes annually about 100,000 tons of beet-sugar molasses. As nearly all the continental beet molasses is desugarized by the strontia process, this would indicate that over 100,000 tons of strontium hydroxide are employed in Germany alone. It must be remembered, however, that this does not indicate the annual consumption, which is probably very much less than this figure, owing to the fact that the strontium compounds are nearly all recovered by various regenerative processes, so that the percentage of loss is rather small.

DOMESTIC PRODUCTION.[1]

In 1916 about 250 tons of strontium-bearing material was produced in the United States, mainly from Arizona, California, and Washington. In previous years there had been no domestic production, the demand being supplied by the importation of English celestite. The embargo placed by the British Government in 1916 on the exportation of all strontium compounds, combined with other abnormal conditions produced by the war, has stimulated domestic production and has awakened considerable interest in domestic sources of strontium.

THE CHIEF COMMERCIALLY PRODUCTIVE STRONTIUM DEPOSITS OF EUROPE.

Those engaged in prospecting and developing new deposits of strontium are greatly interested in all information on the geology and economic features of the world's commercially productive strontium deposits. The deposits of England, Germany, and Sicily have heretofore dominated the world's strontium market. As the information concerning these deposits has been so far nowhere brought together, it is accordingly assembled in the following pages in summarized form. The American deposits are fully described by Phalen[1] and by Hill.[2]

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[1] Hill, J. M., Strontium: U. S. Geol. Survey Mineral Resources, 1916, pt. 2, p. 186, 1917.

CELESTITE DEPOSITS OF THE BRISTOL DISTRICT, ENGLAND.[3]

The productive celestite deposits of England are near Yate, in Gloucestershire, 10 miles northeast of Bristol. Formerly celestite was produced at several other localities in Gloucestershire and also in Somerset, south of Bristol.

English celestite is unsalable if it contains less than 90 per cent strontium sulphate. The output has fluctuated greatly; the maximum annual output, 32,281 long tons, was made in 1902, and in recent years it has ranged from 4,761 to 19,370 long tons. The output and value of English celestite is shown in the following table:

Celestite produced in England, 1910–1914.

	Quantity (long tons).	Value.[a]
1910	4,761	£3,570
1911	5,869	4,400
1912	19,370	15,020
1913	18,425	14,287
1914	13,157	([b])

[a] Some of these values are reported to be only estimates. [b] Not available.

In explanation of the irregular output of English celestite, Sherlock says:

> It is not unlikely that the more marked of these changes are due to variations in the demand for strontia in the beet-sugar industry. Scheibler seems to have published his strontia process in 1882, and in that year it was announced[4] that a large refinery for sugar was to be erected in Bohemia for working molasses by means of strontia. The undertaking was organized by the refinery at Dessau (the destination of the English strontium), which also had at its disposal the strontianite deposits of Westphalia. It would appear that this process was not wholly successful, and this may be the explanation of the great drop in the value of strontium in 1885. Scheibler invented an improved method in 1886, which has been a success and may explain the irregular rise in output which lasted until 1903. The problem is complicated by the fact that only a limited amount of molasses has its sugar extracted, the greater part being used for cattle food.

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[1] Phalen, W. C., Celestite deposits in California and Arizona: U. S. Geol. Survey Bull. 540, pp. 526–531, 1913.

[2] Hill, J. M., op. cit.

[3] Sherlock, R. L., Celestine and strontianite: Special Reports on Mineral Resources of Great Britain, vol. 3, pp. 41–54; England and Wales Geol. Survey Mem., 1915.

[4] Jour. fabr. sucre, 1882; Jour. Chem. Industry.

The celestite-bearing belt at Yate is about 600 yards wide and 5 miles long. The celestite occurs as irregular masses and lenses localized along a definite horizon in Triassic marl; it occurs also in fissures in the underlying steeply dipping rocks on which the marl was unconformably deposited. The layers of celestite are locally as much as 3 feet thick but pinch out abruptly. Although not continuous, they appear again farther on at the same level.[1] Gypsum occurs near the celestite masses but not in them.

The celestite is prospected by probing with a boring tool. If none is found to a depth of 9 feet, a new site is chosen. If celestite is found, a pit is dug and enlarged as the mineral is extracted. If the floor on which the marl rests is reached, a crowbar is used to find any mass of celestite that may occur in the bedding planes of the underlying rocks or in cavities in them. One pit may yield several thousand tons, whereas the next may yield very little. About one half the celestite obtained comes from the marl and the other half from the underlying rocks.[2] The workings are all shallow, and, as they are on flat ground, they become flooded during the winter, so that operations must be suspended.

SICILIAN CELESTITE DEPOSITS.

Celestite occurs in the Sicilian sulphur deposits in association with crystallized sulphur, aragonite, calcite, and gypsum.[3] These minerals are localized in fissures, where they have been deposited from solutions that have partly dissolved and redeposited the minerals of the primary sulphur and gypsum beds, which are of upper Miocene age. At certain localities the celestite occurs in considerable quantities and is worked for export. At the Grotta Calda mine layers of celestite 7 to 8 centimeters thick alternate with beds of limestone and sulphur.

The production is not accurately known but at times is fairly large, as considerable quantities have been shipped to Germany. According to Sherlock[4] the price of English celestite "is kept down by the extensive deposits in Sicily, which ordinarily do not pay for transport on mule back to the coast. But when the price rises a little above the present figure the Sicilian deposits come on the market and prevent further advance."

WESTPHALIAN STRONTIANITE DEPOSITS.[5]

The German strontianite deposits are in the Münster district, Westphalia, in western Prussia. As long ago as 1834 strontianite was known to occur here, but not until 1874 were the deposits largely or systematically worked. In the early seventies the managers of the sugar refinery at Dessau decided to use the strontia process for extracting the sugar from molasses, and in 1874 the strontianite deposits of the Münster district were examined with a view to determining whether a large and steady production of strontium could be attained. As a result of favorable recommendation, the deposits were developed by the refinery, and a veritable boom set in. At the height of the mining activity, in 1883, 45 mines were in operation and 2,350 men were employed. The mine owned by the Dessau refinery employed alone 600 men. The strontianite at the end of the seventies commanded a price of $100 a ton. In 1910 there were only two mines in operation, which produced 800 tons of strontianite, reckoned on the basis of 100 per cent strontium carbonate, the average value of which was $40 a ton.[1]

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[1] Baker, B. A., Celestine deposits of the Bristol district: Bristol Naturalists Soc. Proc., vol. 9, p. 162, 1901.

[2] Sherlock, R. L., op. cit., p. 47.

[3] Stutzer, O., Die wichtigsten Lagerstätten der Nicht-Erze, pp. 206–207, 1911.

[4] Sherlock, R. L., op. cit., p. 54.

[5] Venator, Emil, Ueber das Vorkommen und die Gewinnung von Strontianit in Westfalen: Berg. u. Hüttenm. Zeitung. Jahrg. 41, pp. 1–4, 11–13, 18–19, 1882. Dammer, B. and Tietze, O., Die nutzbaren Mineralien, Band 1, pp. 463–467, 1913.

The strontianite-bearing area is 24 square miles in extent. The prevailing country rock is a rather firm bluish-gray calcareous shale ("marl") of Cretaceous age. This formation is traversed by a large number of veins, which generally dip from 70° to 90°, or nearly at right angles to the bedding. The larger veins are remarkably persistent, some of them being traceable for more than a mile. They vary abruptly in thickness, ranging from a mere film of clay to bodies 6 feet and exceptionally 10 feet thick. The vein filling consists of strontianite, calcite, shale fragments, and a small amount of pyrite. Many of the veins are symmetrically banded, the calcite forming the layers adjoining the walls and the strontianite occupying the central part of the veins. The strontianite occurs in the veins as lenses also, some of which attain as much as 60 feet in length. The barren stretches between such strontianite lenses are commonly rather long. In depth the veins contain more and more calcite, and this impoverishment, together with the heavy inflow of water, made them become unprofitable, so that they were unable to survive competition with English celestite. The deepest working attained a depth of 175 feet. Only two veins, which range from 8 to 12 inches in thickness, were being worked in 1911.

SUMMARY AND CONCLUSIONS.

The strontianite deposits near Barstow, Cal., have been formed by the replacement of lacustral limestone beds that are interstratified in the clays of the middle member of the "Barstow formation," of upper Miocene age. They thus differ considerably from the only other commercially productive strontianite deposits—those of the Münster district, Westphalia—which consist of a series of steeply dipping veins cutting horizontal marine calcareous shales of Upper Cretaceous age. They resemble the Westphalian deposits in one fundamental respect, however—they were formed later than the strata that inclose them.

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[1] Schulze-Höing, Der Strontianitbergbau im Regierungsbezirk Münster: Glückauf, vol. 48, pp. 518–519, 1912.

The California strontianite occurs in two forms. The high-grade strontianite is crystallized in slender needles which make up radial and spherulitic aggregates; the lower-grade material resembles exceedingly fine grained, dense gray limestone. No great quantity of strontianite is in sight at any one point, but the number of places at which strontianite has been found is surprisingly large.

A considerable amount of strontianite can readily be obtained by gathering the high-grade float from the numerous strontium-bearing beds. Deep mining will be impracticable, if not impossible, on account of the loose, unconsolidated condition of the clays in which the strontiferous beds are inclosed, and all operations will necessarily be restricted to open-cut work. An initial shipment of 7 tons of high-grade strontianite was made early in 1917 to a manufacturing chemist at Los Angeles to be worked up into strontium salts.

The requirements of the beet-sugar industry have hitherto dominated the world's strontium market. These requirements centered in Germany, which supplied the strontium hydrate required not only by its own refineries but also by those of France and doubtless those of Russia. The German demand and the English supply of celestite have in the past determined the market price of strontium ore. These conditions have been gravely affected by the war and the British embargo on the exportation of all strontium compounds, crude or manufactured. As a result the production and search for new deposits in the United States has been strongly stimulated, but the permanence of the domestic strontium industry would seem to depend on the adoption of the strontia process by American beet-sugar refineries; and this, in turn, probably depends on the assurance of a regular supply of strontium hydrate at a reasonable price.

In recent years strontianite has commanded more than three times the price of celestite. Therefore, although English celestite containing less than 90 per cent of strontium sulphate is unsalable, it seems reasonable to expect that strontianite ore carrying considerably less than 90 per cent of strontium carbonate would find a market; and, in fact, recent quotations show that material containing as low as 83 per cent of strontium carbonate is acceptable.

In conclusion it may be pointed out that the discovery of strontianite in the lake beds of the Barstow syncline suggests the possibility that similar deposits may be found wherever the same series of lake beds occurs in the region adjacent to Barstow. The areas in which these beds are likely to occur have been outlined by Pack[1] and are shown on Plate XI, which is reproduced from his report.

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[1] Pack, R. W., Reconnaissance of the Barstow-Kramer region, Cal.: U. S. Geol. Survey Bull. 541, pp. 141-154, 1914.

POSSIBILITIES FOR MANGANESE ORE ON CERTAIN UNDEVELOPED TRACTS IN THE SHENANDOAH VALLEY, VIRGINIA.

By D. F. Hewett, G. W. Stose, F. J. Katz, and H. D. Miser.

SCOPE OF INVESTIGATION AND REPORT.

Studies of ore deposits aim to interpret the associations of ores, in order that the systematic exploitation of known deposits or the search for unknown ones may be carried on intelligently. Such studies attempt to determine the source of the materials that make up the ore and associated minerals, the conditions that determine the favorable places for accumulation, the processes by which the accumulation has been accomplished, and the subsequent processes that have affected the deposit or brought it to view at the surface.

It is apparent that any attempt to determine areas that may contain ore deposits now unknown must be based upon a sound even if incomplete hypothesis concerning the origin and mode of occurrence of the ores, and such a hypothesis can be formulated only after many deposits of the particular ore sought have been thoroughly explored and studied.

Manganese minerals are widely distributed in Virginia, and a fairly complete explanation of the origin of the large deposits, which are sources of ore, will be possible only when many deposits have been examined in detail. Although much remains to be learned in future work, it is believed that sufficient is now known concerning some types of these deposits in Virginia to warrant the direction of effort toward exploration in areas where unknown deposits may be found.

This report aims to present briefly the results of field work in a part of Virginia where many manganese deposits are known. The examination was directed toward the discovery of areas likely to contain manganese, with the aid of data gathered in a study of the geologic relations of known deposits. The field work was done in cooperation with the Geological Survey of Virginia. As it has brought forth much information concerning the nature and structure of the rocks associated with the manganese ores, which may greatly aid the operators of producing mines, a more detailed report will be published later by the Virginia Survey.

AREA EXAMINED AND METHODS EMPLOYED.

Northwestern Virginia has long been the source of much of the manganese ore mined in the United States, and at times it has been the scene of active prospecting in the hope that other extensive deposits like that at the Crimora mine might be discovered. The manganese deposits lie along the east side of the Shenandoah Valley, at the foot of the Blue Ridge. For the present investigation a narrow belt was selected extending from Front Royal at the north to a point about 10 miles southwest of Waynesboro at the south. (See fig. 26.) This strip is about 85 miles long and averages 4 miles wide, and the Crimora mine occupies a central position in it. A preliminary geologic map of the area has been prepared, and this will be published in the report of the Geological Survey of Virginia.

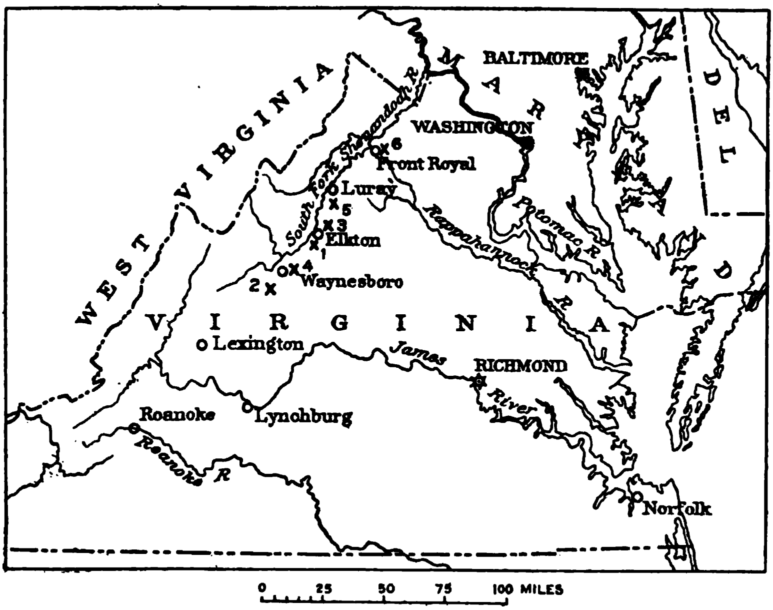

FIGURE 26.—Index map of northern Virginia, showing location of undeveloped tracts recommended as favorable for prospecting for manganese. Tracts are numbered in the order of prospective promise.

The method of study was very similar to that which would have been employed in making a detailed areal map of the region. Traverses were run along the roads and up the streams that cross the belt nearly at right angles to the trend of the bedded rocks. By this means the attitude of the beds was determined and the boundaries of the rock formations were located. The adjacent mountains were climbed where more information was needed or where a general view was desired for the purpose of location. This was essential in many places on account of the inadequate exposures of the rocks in the lowlands and the necessity of resketching the topographic base map where it was inaccurate. Where the rocks were found so broken by weathering or so covered by rock waste that the bedding could not be determined, the structure was inferred by the study of surface forms and the distribution of distinctive débris derived from the several formations.

In addition to the traverses for the purpose of making the map and determining the structure of the rocks, manganese and iron mines, prospect pits, and holes of any sort where information as to the relation of the ore to the bedrock might be observed were examined. At only a few places was the unaltered limestone in the mine pits visible, but the relation of the ore to the residual clay and to the wash was carefully scrutinized. The clay in most of the deeper mines and in some of the shallow pits was found to preserve the original bedding of the impure dolomite and limestone, so that the structural relations of the ore to these rocks could be determined.

THE MANGANESE DEPOSITS.

GENERAL FEATURES.

The known manganese deposits of this part of Virginia are masses of oxides that are associated with rocks of several different types and have diverse structural relations. Some bodies of the oxides are rather large and so pure that they may be mined and shipped without prelminary treatment. Other masses are composed of nodules disseminated through clay in proportions that have a wide range. The material from such deposits must be washed to procure ore of high enough grade to warrant shipping.

A complete discussion of the origin of the deposits should include geologic data of several kinds, such as the distribution of manganese-bearing rocks and minerals, the chemical properties of manganese compounds and natural minerals, the character of the ground water of the region, the characteristics and stratigraphic relations of the rocks with which the ores are associated, the local structure of the rocks, and the surface features resulting from the erosional processes that have affected the region. Brief statements concerning data of the last three kinds only are presented in this report, as they are used in outlining favorable areas for the accumulation of the ores.

ROCKS WITH WHICH THE ORE IS ASSOCIATED.

The rocks which occur in the vicinity of the manganese deposits of the Blue Ridge and adjacent part of the Shenandoah Valley include sandstone, shale, limestone, and dolomite and the older crystalline rocks on which these rest. The oldest crystalline rock present in the area is granite. The other crystalline rocks are greenstone, greenstone schist, and sericite schist, which were originally molten lavas. The massive greenstone is very resistant to weathering—that is, it is not readily soluble in water nor easily broken up by frost and rain—and therefore it forms the highest summits of the Blue Ridge throughout this area.

Immediately overlying the crystalline rocks are sandstones and quartzites, composed in part of unassorted débris derived from the disintegration of the older crystalline rocks. These beds range from soft arkose through harder arkosic sandstone to hard gray sandstone and dark ferruginous quartzite. With them are associated beds of slaty argillaceous sandstones. Some of the basal beds have rounded grains and small pebbles of quartz, which are usually clear and transparent, though some have an opaline blue color. Besides quartz there are grains of feldspar, generally chalky white from weathering, and considerable clay and iron oxide. A spotted sericite schist, representing a thin amygdaloidal lava flow, occurs at several places interbedded with the lowest sedimentary beds. These rocks have been called the Unicoi formation in northern Tennessee, and that name will be used in this report. They are equivalent to the Weverton sandstone and Loudoun formation of Maryland and northern Virginia. Their thickness in this area is estimated to be 1,750 to 2,000 feet. The formation is best exposed in the cuts of the Southern Railway 4 miles east of Front Royal but is also well shown on the Simmons Gap road south of Elkton and elsewhere in the belt between the main Blue Ridge and the front foothills.

Overlying the Unicoi formation are dark-gray shales, slates, and thin sandstones which in northern Tennessee constitute the Hampton shale. The shales and slates are mostly sandy and weather to hackly outcrops, so that in many places their original character and bedding can not be clearly discerned. Some of the shale is dark and banded but weathers to soft buff rock. The formation is the same as the lower part of the Harpers shale of northern Virginia. It is estimated to be about 400 feet thick in this area but may be much thicker, as it is in general highly folded. Typical rocks of the Hampton and Unicoi formations are easily distinguished, but the two formations were not separately mapped everywhere in the field, because there are shaly rocks in the Unicoi and hard sandstones and arkoses in the Hampton. All these rocks weather more easily than either the underlying greenstone or the overlying massive white quartzite, so that they form depressions or subordinate ridges between the main Blue Ridge on the east and the outer foothill ridges on the west.

The next higher formation is a massive white quartzite, the outcrops of which make prominent ridges in this region. It is here called the Erwin quartzite. The western foothills of the Blue Ridge throughout most of the area are composed of this rock, and in many places it forms the front ridges. The formation in this region is generally made up of three massive cliff-making ledges separated by thinner-bedded sandstones. The thickness in the measured section given below, the best-exposed section in this region, is 500 feet, but it appears elsewhere to be much greater, possibly 1,000 feet.

Section of Erwin quartzite in Blue Ridge near Stanley, Va.

	Feet.
White sandstone full of scolithus; crumbles readily to sand. Rarely exposed in place. Upper layers harder; weather red to rusty and porous	120
Upper cliff: Hard white thick-bedded vitreous quartzite. Contains some scolithus	40
Partly covered, probably crumbly white sandstone	90
Middle cliff: Hard thick massive beds of bluish-white vitreous quartzite	80
Covered, probably crumbly sandstone	70
Lower cliff: Hard white vitreous quartzite. Contains some scolithus	100
	500

The cliff-making ledges consist largely of massive beds of dense white quartzite, some of which are 15 to 20 feet thick without a visible trace of bedding. Many of the beds contain casts of worm tubes (scolithus), and as these were vertical when the sediments were deposited they may be used to determine the bedding of the rocks, which is at right angles to them. This formation is the same as the Erwin quartzite of northern Tennessee and has also been correlated with the Antietam sandstone of northern Virginia. It is believed, however, to represent not only the Antietam but also a lower quartzite, the Montalto quartzite of southern Pennsylvania, which is a member of the Harpers shale.

In the Shenandoah Valley the Erwin quartzite is overlain by a great thickness of limestone and shale, but only those beds immediately adjacent to the mountain front need here be considered. The formation that normally lies above the Erwin quartzite—the Shady dolomite—is composed largely of coarse dolomite containing chert nodules and beds of impure shaly limestone. Because of the solubility of the dolomite it readily breaks down into grains and finally weathers into red clay and is generally not visible at the surface. It therefore forms a deep-red granular and clayey soil containing chert fragments and underlies low valleys. Some yellow laminated clay or ocherous layers at the base represent banded argillaceous limestones. Unaltered dolomite has been exposed only in a few shafts and tunnels in the region. The formation is the same as the Shady limestone of northern Tennessee and is equivalent to the Tomstown limestone of southern Pennsylvania and Maryland. It is reported to be 1,800 feet thick in the vicinity of Natural Bridge, and it has probably about the same thickness here.

The next recognized formation of the limestone group is a shale called Watauga in northern Tennessee. Its characteristic color is reddish purple, but in this area it is generally so much weathered that it is buff colored. In places it is weathered to purple and buff banded ocherous clay, as at the ocher mine 10 miles southwest of Luray. It contains thin calcareous shales and blue limestone beds and in places thinly laminated ripple-marked sandstone, which is best displayed east of Front Royal. It is the equivalent of the Waynesboro shale of southern Pennsylvania and Maryland, which is conspicuously purple and sandy. The thickness in this area could not be determined, because of poor exposures. The formation is reported to be 900 feet thick in the vicinity of Natural Bridge, where it is better exposed, but it does not appear to be so thick in this area. Above the Watauga shale are limestones and dolomites that have not been differentiated in this area, and as they need not be considered in the present connection, they will not be described.

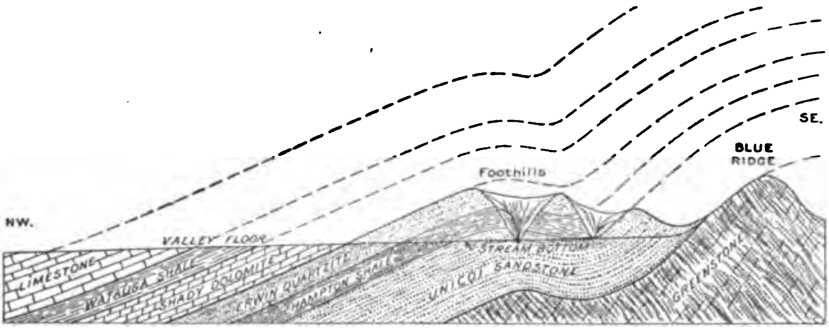

FIGURE 27.—Generalized structure section of the west front of the Blue Ridge and the adjacent part of the Shenandoah Valley, showing the normal relations of the rocks and their former extent (dashed lines) before removal by erosion.

All the sedimentary rocks above described are geologically very old. No fossils, except the worm tubes in the Erwin quartzite, were found in them in this area, but casts of shells and other fossils have been found in the equivalent formations elsewhere, and they are therefore known to belong in the Cambrian and to be among the oldest fossiliferous rocks known in the eastern part of the continent.

The sediments were nearly horizontal when they were laid down in the sea. The beds are now in most places steeply inclined and folded into long troughs (synclines) and arches (anticlines) whose axes are parallel to the northeasterly trend of the mountain ridges. (See fig. 27.) After being folded and wrinkled the rocks were worn down by processes of atmospheric erosion, and the softer and more soluble rocks were removed from the higher regions. The underlying quartzites, shales, and greenstones were thus exposed and, because of their resistance to erosion, now form the mountains, whereas the limestone underlies the valleys. A generalized cross section showing the rocks of the region as they are now and their extent before they were eroded is given in figure 27.

The manganese deposits are not confined to a single thin group of beds but lie in or over beds that range from the upper part of the Erwin quartzite to the lower part of the Watauga shale, stratigraphically 2,000 feet higher. Most of the deposits, however, occur in banded clays that are believed to have been derived by weathering in place from the lower 200 feet of the Shady dolomite.

RELATION OF DEPOSITS TO STRUCTURAL FEATURES.

Manganese oxides are widespread in the Shenandoah Valley, but as most of the rocks near by are deeply decayed, the structural associations of many small bodies of the oxides are obscure. Studies of a number of deposits that were large enough to warrant extensive exploration, however, show that at least five structural types may be recognized and that in most places the local structure of the adjacent rocks has determined the form of the deposits and in large measure their areal extent and their persistence below the surface.

The five types of deposits will be briefly described. Figure 23 shows cross sections of four deposits which have been studied recently and which probably include those types that are sources of most of the ore now mined in northwestern Virginia.

1. The commonest type of deposit in the belt under consideration is that represented at the old Kendall & Flick shaft, south of Elkton, but also shown at the Vesuvius mine, 1¼ miles northeast of Vesuvius, Rockbridge County, and elsewhere in the region (fig. 28, B). These deposits occur in a 200-foot zone of decomposed shale and cherty dolomite that overlies the upper beds of the Erwin quartzite, where the beds dip toward the Shenandoah Valley at angles that range from 30° to 60°. The structure near these deposits may be termed monoclinal, as all the beds are similarly inclined. In such localities the upper surface of the Erwin quartzite forms the slope of a conspicuous straight ridge, and float ore from the deposits is found over the gentle slopes near by on the northwest. Under these structural conditions irregular bodies of manganese oxides are found here and there in a narrow belt of decomposed shale and dolomite parallel to the outcrop of the Erwin quartzite. The bodies of manganese oxides appear to have no relation to the transverse ravines that rise in the Blue Ridge and cross the quartzite. So far as available records show, no deposits of manganese ore or manganiferous iron ore occurring under these conditions in this area have yielded more than 25,000 tons, and many have been abandoned before producing as much as 5,000 tons.

this type is now being explored on the Kennedy property, 3 miles southwest of Sherando, Augusta County. In these deposits manganese oxides replace the clay zones of sediments that fill an ancient river channel (Midvale) or that form an ancient alluvial fan or gravel terrace (Kennedy). It is a coincidence that the Kennedy deposit is near the outlet of an ancient stream that rose in the high ridges several miles to the south and flowed in a trough directed toward the deposit. Such deposits are flat masses that conform to the depressions in which the sediments were laid down. Exploration by drilling at the Kennedy mine is reported to show the presence of a large quantity of ore, and it is possible that here, as with deposits in troughs, the size may depend upon favorable local structural features.

The field work on which this report is based was directed especially toward the interpretation of the structure of the beds making up the Erwin quartzite, Shady dolomite, and Watauga shale. The tracts in the belt examined that are considered favorable to the accumulation of manganese or manganiferous iron ore are those which are underlain by troughs of the upper beds of the Erwin quartzite, from the surface of which the products of decay of the overlying Shady dolomite have not been removed. The six tracts that are described in the following pages fulfill these conditions, but the troughs are considered favorable in proportion to the size of the area that has drained into them, or to the abundance of float ore present and the thoroughness of the decay of the rocks over the Erwin quartzite.

A number of faults have been recognized in this belt, but as the factors which determine the parts of the fault zones that are favorable to accumulation of ore are not known, and as the only deposit known to lie along a fault is not large, it would not be wise to direct exploration along such faults.

RELATION OF DEPOSITS TO SURFACE FEATURES.

In a recent report[1] it has been suggested that several manganese deposits in the region between Potomac River and Midvale, Rockbridge County, Va., occur under conditions that make it appear that they were formed during or soon after the period in which the valley-floor peneplain was being established. This peneplain has been considered to be of early Tertiary age and for brevity it will here be referred to as the early Tertiary peneplain. It was also noted that several deposits crop out at the level of this plain, without regard to the extent to which the plain was locally dissected. The present investigation has shown that the outcrops of a number of additional deposits lie close to the position of this peneplain, but also that the lowest point of one deposit—that at Red Mountain, northeast of Vesuvius—occurs 400 to 500 feet above the level of this plain, and that the surface near the Lyndhurst mine is not 50 feet below the early Tertiary plain, as stated in a previous report by the senior author,[1] but nearly 250 feet below it. Therefore, while the conditions during or soon after the early Tertiary peneplanation appear to have been particularly favorable to the accumulation of certain deposits of manganese and possibly of iron ores, others were probably formed at an earlier and some at a later period.

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[1] Hewett, D. F., op. cit., pp. 37–71.

Evidence collected during this investigation shows that although four periods of planation may be recognized,[2] the recent physiographic history has probably been even more complex.

Although field work has shown that the Midvale and Kennedy deposits are in alluvial material laid down near the level of the early Tertiary plain and the region contains many remnants of gravel on this plain, there is no way of recognizing, in advance of exploration, the places where these gravels may contain deposits of manganese ore.

According to the hypothesis previously stated, that troughs present the most favorable structure for the accumulation of manganese ores, those troughs which pitch at a low angle under the early Tertiary plain would be the most favorable, and the parts of the troughs most likely to receive the deposits should be those where the top of the Erwin quartzite is not more than 300 feet below the present surface of the ground.

ORIGIN OF THE DEPOSITS.

A hypothesis of the origin of the manganese deposits of the region is here presented briefly, in so far as it bears on the conditions that are most favorable for the accumulation of manganese oxides. The purpose of this report does not permit the presentation of evidence bearing upon some phases of the hypothesis.

Definite evidence concerning the source of the manganese that now makes up the workable deposits is lacking; but, from the data at hand, it appears that the manganese was originally widely disseminated as carbonate in the dolomite and limestone and possibly in silicates in other rocks found in the neighborhood of the deposits. The manganese was dissolved as bicarbonate and transported along established channels of circulation to the places where the oxides are now found, in clays produced by the previous decay of sericitic shales, limestone, and dolomite. The oxides were probably deposited when and where the solutions containing manganese bicarbonate met oxygen-bearing waters. Manganese oxide appears to have been deposited largely by replacing the clay, although small quantities were deposited in open spaces. The largest deposits of manganese were formed in places where the maximum amount of manganese in solution met the most favorable conditions for deposition. Most complete rock decay and, therefore, solution of the maximum proportion of manganese in the rocks are probably attained in regions of low relief having a thick cover of vegetation, under the influence of a warm, moist climate. As the process of solution would be most active in those parts of the region above the average level of streams and above ground-water level, more manganese should be delivered in solution to the belt of country where the ridges and hills meet the plains than elsewhere.

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[1] Hewett, D. F., op. cit., p. 61.

[2] Watson, T. L., Drainage changes in the Shenandoah Valley region of Virginia: Virginia Univ. Philos. Soc. Bull., Sci. ser., vol. 1, p. 355, 1913.

If not diverted by the local rock structure the maximum flow of solutions near the surface would have occurred near or directly under surface stream channels. Where oxidation was possible deposits formed in the stream channels themselves As deeper circulation of surface waters was controlled by rock structure, troughs would have received the maximum circulation, although fault zones might have been locally favored. According to this hypothesis structural troughs were the most favorable channels for circulation, and if suitable conditions for oxidation and deposition existed they should be the most favorable places for accumulation.

Many reports have been published which describe briefly the associations of manganese ore in certain mines in Virginia, but most of the available information concerning the stratigraphic and structural relations of the deposits in Virginia is contained in reports that are based on comprehensive studies of many deposits in a large area.[1] The relation of the hypotheses of origin of the manganese deposits set forth in these reports will be discussed in a later report.

TRACTS RECOMMENDED FOR EXPLORATION.

BASIS OF RECOMMENDATIONS.

Descriptions of six undeveloped tracts along the west front of the Blue Ridge are presented below. These tracts appear to present features favorable for the accumulation of deposits of manganese and manganiferous iron ores, and prospecting with the view to discovering such deposits is recommended. Formerly such deposits were prospected by means of pits and trenches, but recently improvements in methods of employing the churn drill make it most useful for this purpose, and several operators use it extensively. Even if deposits should exist under these tracts, they may be covered by gravel or wash from the neighboring slopes, as at the Crimora mine, and exploration by drilling is peculiarly adapted to such conditions.

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[1] Penrose, R. A. F., Manganese, its uses, ores, and deposits: Arkansas Geol. Survey Ann. Rept. for 1890, vol. 1, pp. 401–412, 1891.

Hall, C. E., Geological notes on the manganese ore deposits of Crimora, Va.: Am. Inst. Min. Eng. Trans., vol. 20, pp. 46–49, 1892.

Watson, T. L., Mineral resources of Virginia, Virginia Geol. Survey, 1907.

Harder, E. C., Manganese deposits of the United States: U. S. Geol. Survey Bull. 427, 1910.

Hewett, D. F., Some manganese deposits in Virginia and Maryland: U. S. Geol. Survey Bull. 640, pp. 37–71, 1916.

These tracts are regarded as favorable for exploration largely because they have the same structural and stratigraphic features as other areas within which large deposits of manganese and manganiferous iron ores are known and bear a similar relation to the surface. They are described in the order of greatest promise, the one in which the conditions are believed to be most favorable first. Fragments of manganese minerals have been found on the surface of many tracts, but as such fragments are widespread in this region they are not especially significant. Positive assurance that these tracts contain workable deposits of ore can not be given, but to those interested in searching for unknown deposits of these ores the tracts should offer an attractive field.

TRACT 1.

Tract 1 lies 2 miles southwest of Elkton, within a mile of the Norfolk & Western Railway. (See fig. 29.) The west front of the mountains in the vicinity of Elkton has many sharp offsets in its general southwest course. From Swift Run this course is a little south of west for 1½ miles to a point where the mountain front is slightly offset to the northwest. From that point the front runs west-southwest across Hawksbill Creek for 1¼ miles to a sharp offset to the east of about half a mile. The southwestward course then continues for three-fourths of a mile but is interrupted by a second sharp offset to the east of about a quarter of a mile. At Gap Run, three-quarters of a mile beyond, the mountain front is slightly offset in the opposite direction, to the west, but the southwest trend is maintained. At Swift Run the mountain front is offset to the southeast, and beyond Elk Run the front ridge breaks down to low knolls for over a mile.

Along the west flank of the mountains, immediately west of the line just traced, there are gravel-covered terraces that slope toward Shenandoah River and are deeply trenched by cross streams. No rock exposures occur in the gravel-covered belt, but several mine shafts and test pits show that it is underlain by lower members of the Shenandoah group of limestones (Shady dolomite and Watauga shale). The gravel-covered area is 1 to 1¼ miles wide, except for a short stretch at the mouth of Hawksbill Creek, where it is reduced in width to about a quarter of a mile by the eastward bend of Shenandoah River. West of the gravel terraces at the mouth of Hawksbill Creek, especially along Shenandoah River, there are exposures of the Watauga shale and overlying beds of limestone.

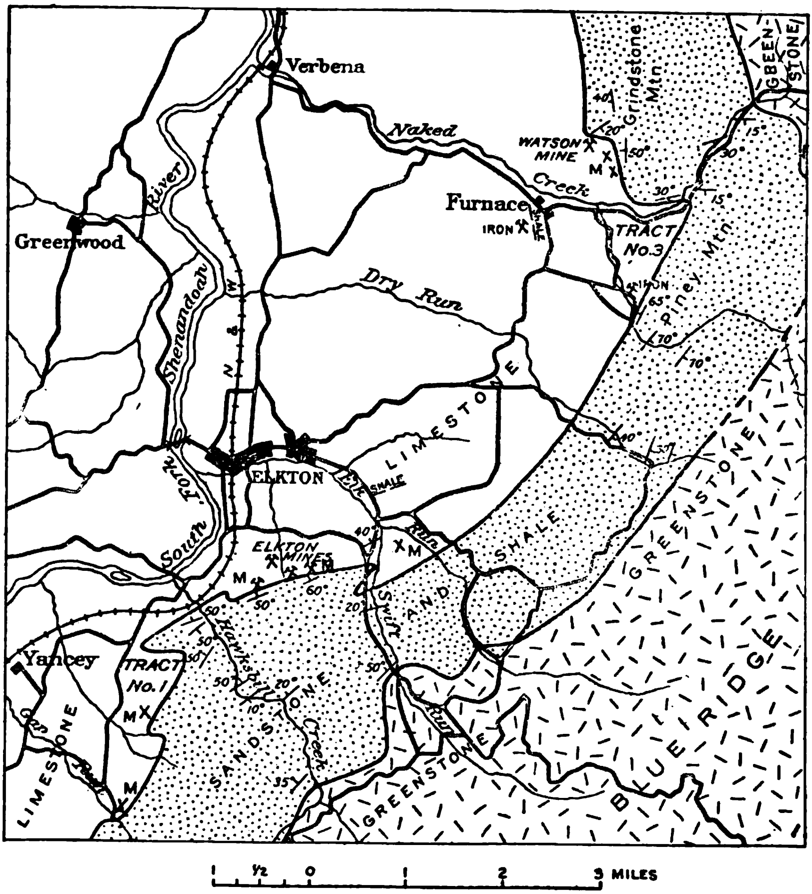

FIGURE 29.—Sketch geologic map of region near Elkton, Va., showing location of tracts 1 and 3.

The western foothills of the Blue Ridge are made up of white quartzite (Erwin), whose structure determined the irregular course of the mountain front. Thus from Swift Run westward for 1½ miles, where the mountain front is straight and trends west-southwest, the quartzite beds strike about parallel to the mountain front and dip 50°–60° NW., passing under the limestone of the valley. The small offset in the mountain front at Hawksbill Creek and the larger one east of Yancey are produced by a detached anticlinal ridge of quartzite which is separated from the main quartzite ridge by a shallow synclinal valley. Both the anticline and the syncline plunge sharply northeast just east of Hawksbill Creek, and the quartzite abruptly passes under the limestone of the valley. Southwest of Hawksbill Creek the folds plunge more gently southwestward, and the quartzite again passes below the level of the gravel-covered plain in that direction. The syncline widens in this direction, as the main ridge of the mountain here strikes more southerly and diverges from the outlying ridge, and the limestone embayment is therefore large and open. The offset in the mountain front three-quarters of a mile farther south is apparently produced by two similar though smaller folds, which plunge south, and the northwest offset at Gap Run is formed by two other flat, gentle folds, which plunge north. The offset east of Swift Run is apparently produced by a northeastward-plunging anticline and syncline, for, although the bedding in the sandstone was not observed, the rocks seen along the road crossing the syncline are believed to be the basal sandy beds of the limestone group. Beyond this offset the mountain front is straight, although the front ridge breaks down beyond Elk Run, where the quartzite is weakened by crushing and probable minor faulting.

Although the white quartzite beds have a general steep westerly dip on the front foothills they flatten out toward the east and cap the tops of several spurs and ridges some distance back from the front, where they are nearly horizontal or even lie in gentle synclines. To the east of and therefore beneath the white quartzite there are shales and arkosic sandstones which are somewhat folded and form a belt half a mile to 1½ miles wide. These basal Cambrian beds rest upon pre-Cambrian greenstone and greenstone schists which generally form the main mass of the Blue Ridge.

There is a group of manganese mines about 1 mile south of Elkton, which will be referred to as the Elkton mines. The old workings are known as the Kendall & Flick mines and include the Niesswaner shaft and Bartell shaft, which have been described by Harder[1] and Hewett.[2] One of the mines is now being worked by the United States Manganese Co. These mines are on a terrace at the base of the quartzite ridge between Swift Run and Hawksbill Creek. Three of the mines, including the easternmost, which alone is active at present, lie close to the top of the northwestward-dipping quartzite, and apparently there is no synclinal structure of the bedrock that determined the concentration of these deposits of ore. As the outer mine, which is about 1,200 feet from the base of the mountain, struck the purple Watauga shale in its deep shaft, the steep westward dip of the beds probably continues out that far, and the small syncline at Hawksbill Creek must therefore plunge steeply northeastward. Just east of Swift Run there is a manganiferous iron prospect which is in strike with the three Elkton mines, but the embayment to the south, between the prospect and the quartzite ridge, which is covered with mountain wash, has not been prospected so far as known and may be worthy of investigation, as the structure of the inclosing rocks is apparently synclinal and favorable for the accumulation of ore.

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[1] Harder, E. C., Manganese deposits of the United States: U. S. Geol. Survey Bull. 427, 1910, p. 57.

[2] Hewett, D. F., Some manganese mines in Virginia and Maryland: U. S. Geol. Survey Bull. 640, pp. 61–67, 1916.

Southeast of Yancey a manganese prospect north of the small run has been opened by J. H. Crawford and another south of the run by W. B. Yancey. These two prospects have direct bearing on the tract to which particular attention is here directed. The Crawford prospect shaft, which is 75 feet deep, is on the south side of the embayment in the mountain front 1½ miles east of Yancey station on the Norfolk & Western Railway. This embayment is a triangular area about half a mile long and covers about 180 acres. It lies in the reentrant angle between the white quartzite ridges locally called Little Piney Mountain (on the northwest) and Big Piney Mountain (on the southeast). In the saddle between these hills the upper quartzite beds of the Erwin formation lie horizontal in the bottom of the syncline. The quartzite hills diverge toward the southwest, and the syncline plunges in the same direction, so that the trough between the hills incloses the overlying Shady dolomite. At the Crawford shaft, half a mile south of the head of the trough, manganese nodules occur in red clay with chert fragments, which is the characteristic residuum of the Shady dolomite. The entire embayment, therefore, is probably underlain by the Shady dolomite, but it is completely covered by wash from the quartzite mountains. The only means of determining the thickness of the wash and the presence of manganese ore beneath the alluvial covering is by drilling or by digging test pits. The synclinal structure of the quartzite in the surrounding mountains, the favorably located basin filled with wash and underlain by gently dipping beds of the Shady dolomite or its residual clay, and the known presence of manganese ore in the trough justify the recommendation that this triangular area be thoroughly prospected for manganese.

The conditions in the embayment in the mountain just south of this tract are not so well determined. The structure of the quartzite hills around the offset at the north end of the embayment is obscure and is inferred chiefly from the topography, but at the offset at the south end, just north of Gap Run, the quartzite lies in a very shallow, broad syncline. The alluvial filling in this embayment appears to be heavy, but the Shady dolomite or its residual red clay is probably present, as the manganiferous nodules in the Yancey prospect pits occur in red pebbly clay, although chert fragments, such as are characteristic of the Shady dolomite were not seen in it. This area, though not as promising as the embayment east of Yancey, still has sufficiently favorable indications to suggest that further prospecting should be done in it.

TRACT 2.

Tract 2 lies between two spurs of the Blue Ridge about 3 miles southwest of Sherando and 6 miles south-southwest of Lyndhurst, in Augusta County. (See fig. 30.) It is about midway between the Kennedy mine, to the northwest, and the Mount Torry mine, to the southeast, and is drained by Mills Creek. A lumber railroad over which ore from these two mines is shipped passes just north of the tract and joins the Norfolk & Western Railway near Lipscomb. A spur of the lumber road formerly ran southwestward up Mills Creek, but the rails and ties have been removed.

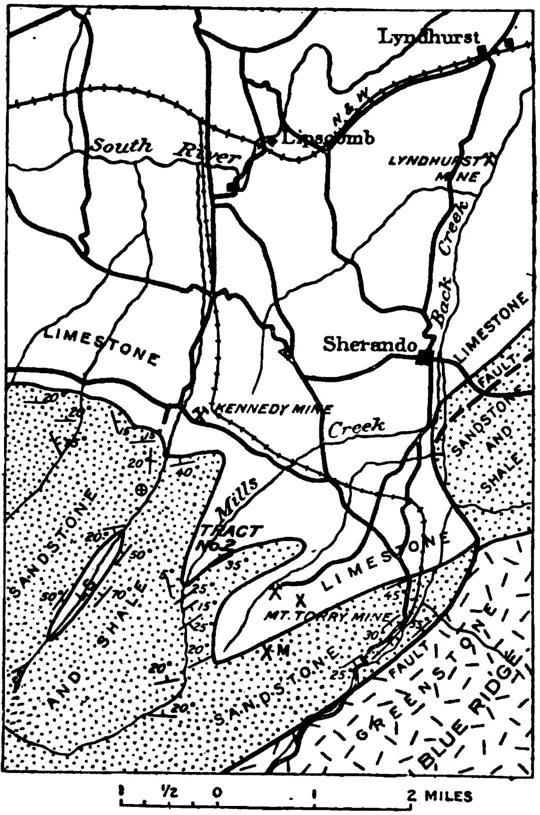

FIGURE 30.—Sketch geologic map of area south of Lyndhurst, Va., showing location of tract 2.

The mountain spurs on both sides of the tract are composed of white quartzite (Erwin), and the structure of each is anticlinal. Both anticlines plunge northeastward, so that in this direction the quartzite descends below the limestones and shales of the Shenandoah Valley. (See fig. 30.) The area between the spurs is a northeastward-plunging syclinal trough and therefore is probably underlain by limestone and possibly some shale, but no outcrops are to be seen, as the surface is covered with quartzite wash from the mountains. The anticlinal spurs on both sides of the plunging synclinal trough diverge to the northeast, so that the limestone belt widens in this direction, forming a wedge-shaped area which is about 1 mile long in a northeasterly direction and about three-quarters of a mile wide between the points of the spurs. This wedge-shaped area merges on its northeast side with the great limestone and shale belt of the Shenandoah Valley.

This synclinal embayment closely resembles the adjacent embayment on the southeast, in which the Mount Torry mine is situated and which also is a synclinal trough. This mine produced a large amount of iron ore 40 or 50 years ago and was abandoned because of the manganese in the ore. Later it was extensively prospected for manganese ore, and some ore was shipped. Both the manganiferous iron ore and the manganese ore are now being mined by a company which has leased the property. This embayment is larger than that on Mills Creek and the syncline is deeper, and although bedrock is not exposed at the surface within the basin, fresh Shady dolomite was encountered in a shaft near the head of the valley.

West of tract 2 there is a smaller embayment of limestone in the mountain front. This embayment occupies a northeastward-plunging synclinal trough, at the mouth of which the Kennedy mine is located. Back in the mountain the syncline deepens and forms a narrow valley which once inclosed limestone between two high, rocky quartzite ridges. This limestone has probably all been removed by erosion, but some may still be present, deeply covered by the quartzite wash. Even if limestone or its residual clay is present, the area is too narrow to expect any large deposit of ore to occur in it, for the ore was probably largely carried out to the mountain front by the former underground drainage and deposited in the clays in which the Kennedy mine is located.

The accumulation of ore in the deposits in which the Mount Torry and Kennedy mines are located was greatly aided by the synclinal structure of the quartzite and overlying limestone. The ore is found in the undisturbed residual clay from the limestone and in overlying clay mixed with quartzite gravel and boulders, where solutions deposited the manganese oxides in crevices or bedding planes, and in nodules and masses replacing the clay. The structural conditions in tract 2 appear to be equally favorable for the accumulation of manganese ore in commercial quantity, and although no manganese ore has been reported there, possibly because of the deep filling of the basin with wash, the favorable structural relations warrant search for the ore. It is therefore recommended that the tract be thoroughly prospected by drilling.

TRACT 3.

Tract 3 lies between Grindstone and Piney mountains, two foothills of the Blue Ridge about 5 miles northeast of Elkton. (See fig. 29, p. 284.) It is chiefly in Rockingham County, but partly in Page County. Naked Creek, which flows near the north edge of the tract, forms the boundary line between the two counties. So far as known, no prospecting for manganese has been done within the area, but the Watson mine is about 1 mile to the north-northwest, and a number of manganese prospects are scattered along the west base of Grindstone Mountain, between it and this tract.

White quartzite (Erwin) is exposed on the crest and most of the west slope of Grindstone Mountain. In general its strike is parallel with the mountain, which trends N. 10°–20° W., and it dips 40°–50° W., passing beneath the limestone and shales that are exposed in the Shenandoah Valley. A small embayment near the south end of Grindstone Mountain is formed by a steeply plunging syncline. No limestone is exposed at the surface in this syncline, but residual clay from the limestone was observed at the Watson mine and in the prospects near by, all of which are in the syncline. This residual clay retains the original bedding of the limestone and incloses decomposed chert that is characteristic of the Shady dolomite. The clay is overlain by and at the top is partly mixed with quartzite boulders, which are especially numerous on the flat wooded spurs that extend southward from the base of the mountain.

Grindstone Mountain ends abruptly at Naked Creek, where the mountain front is offset about a mile to the east and thence continues south in Piney Mountain. The crest and most of the west slope of Piney Mountain are formed of the same white quartzite, which strikes S. 25° W. and dips at a high angle toward the Shenandoah Valley. This offset is caused by an anticline and associated syncline, which are similar to but larger than those at the Watson mine, a mile to the north. The folds are so broad and open and plunge so steeply to the southwest that the strike of the Erwin quartzite here makes two nearly right-angle bends. (See fig. 29.) In the syncline a limestone, which is probably the Shady dolomite, is inclosed above the white quartzite. The limestone is not exposed near the mountain, but a sink hole and red clay residual from limestone seen in a stream bank close to the west slope of Piney Mountain are sufficient evidence of its presence under the covering of wash. Dolomite beds are exposed in Naked Creek south of the Watson mine and also farther out in the valley. The axis of the syncline strikes northeast between the two mountains but lies south of Naked Creek. Along the creek the white quartzite beds, which are north of the synclinal axis, strike N. 70° E. and dip 15°–30° SE. To the east, up the creek the older

Cambrian sandy shale and slate of the Hampton formation and arkosic sandstone and conglomerate of the Unicoi formation crop out beneath the white Erwin quartzite, with similar low southerly dips and nearly east strike. At the base of the Cambrian rocks purple ferruginous sandstone rests on pre-Cambrian greenstone schists.

The ore at the Watson mine consists of concretionary psilomelane and pockets of wad in residual clay of the Shady dolomite. It was mined by means of a shaft and two tunnels and was concentrated in a mill at the mine, but no mining has been done here for several years. Similar ore occurs at the prospect pits along the foot of the mountain for about half a mile southeast of the mine. The mine and prospects are located in a small syncline and are therefore favorably situated for the accumulation of manganese ore, but large, rich deposits are probably not to be expected because of the small size of the syncline. The tract near Naked Creek, however, is larger and more favorably situated for the accumulation of ore, because the syncline from which ore could have been concentrated there is broad and open. Although no ore has been reported from this tract, it is recommended that the tract be thoroughly prospected by drilling or digging pits. It is not advisable to prospect in the stream flats of Naked Creek and its tributary flowing north at the west base of Piney Mountain, for but little, if any, residual clay in which manganese ore would be expected occurs here between the alluvium and the unaltered limestone. Prospecting should be confined to the area between these two creeks.

TRACT 4.

Tract 4 is an irregular lowland area inclosed by low hills, 3 miles northeast of Waynesboro. (See fig. 31.) This region is served by the Shenandoah Valley branch of the Norfolk & Western Railway and the Chesapeake & Ohio Railway, which cross at Basic City.

The boundary between the Blue Ridge and Shenandoah Valley here follows a very irregular but general southwesterly course, which is determined by the irregular structure and distribution of the underlying rocks. Some of the foothills are so low that it is difficult to decide where the boundary between foothills and valley should be drawn. The westernmost foothills of the Blue Ridge are composed of white Cambrian (Erwin) quartzite. Sawmill Ridge and Ramsey Mountain form the main ridge of the white quartzite in this area, and quartzite beds on their west slopes dip 50° W., toward the valley. East of Ramsey Mountain and Sawmill Ridge the white quartzite is underlain by older Cambrian sandy shales and dark arkosic sandstones of the Hampton and Unicoi formations, and east of these are the pre-Cambrian greenstones and schists that compose the larger part of the Blue Ridge. West of the mountain front the

Shenandoah Valley is underlain by Cambrian limestones, dolomites, and shales of the lower part of the Shenandoah group, but these beds are not exposed near the foot of the mountains because of the thick covering of mountain wash consisting of gravel, sand, and clay.

West of Sawmill Ridge there is a low, narrow hill whose anticlinal character is well shown on the road up Sawmill Run, where the anticline plunges south. The narrow valley between this hill and Sawmill Ridge is therefore synclinal and probably contains some Shady dolomite overlying the quartzite. Manganese ore was mined on the Watts property in this syncline many years ago. From the west side of Ramsey Mountain a low ridge that extends 1 mile to the west is made up of several narrow north-south hills with shallow saddles between them. Although no outcrops from which the dip of the rocks could be determined were seen on these hills, they are covered with angular quartzite fragments nearly in place, and the hills are believed to be small anticlines which plunge steeply to the north, toward Sawmill Run, and less steeply to the south. Between the south ends of these hills are small embayments which are structurally synclinal troughs, and two of them are sufficiently large to inclose the overlying Shady dolomite or its residual clay. In fact, fragments of chert derived from the Shady dolomite were found in the alluvial fill of the valleys. The quartzite in the low hills is seemingly that of the upper beds of the Erwin formation.

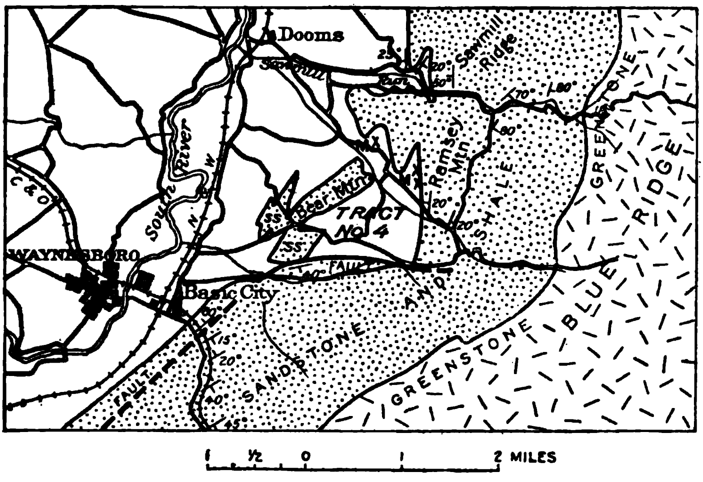

FIGURE 31.—Sketch geologic map of region near Waynesboro, Va., showing location of tract 4.

West of Ramsey Mountain, across an alluvium-filled valley three-fourths to 1 mile wide, is a group of low hills, including a higher one called Bear Mountain. These are quartzite hills which are covered with angular fragments of quartzite and cemented quartzite breccia, but no rock ledges from which the structure could be determined were seen. The hills are believed to be anticlinal in structure and to be made up of several low anticlines in which the quartzite is barely exposed at the surface. Between the individual hills are several small valleys or hollows, presumably occupying synclinal troughs, which, if not too shallow, may contain Shady dolomite. Those on the north and east sides merge with the embayments on the south side of the quartzite hills to the north, which are known to contain chert residual from the dolomite. These structural troughs, which are large and deep enough to contain a considerable body of the Shady dolomite, or its residual clay, are favorable for the accumulation of manganese ore bodies. A prospect pit northeast of Bear Mountain found considerable manganese ore, and two other prospect pits on the west flank of Ramsey Mountain also show ore. In fact, the whole lowland southwest of Ramsey Mountain and southeast of Bear Mountain is believed to be underlain by residual clay from limestone and therefore to have favorable structural conditions for the accumulation of ore. The surface of much of this area, especially the portions close to the quartzite hills, is strewn with small pieces of flinty iron ore, and the soil is markedly red in places. Both of these features indicate the probable presence of the basal beds of the Shady dolomite, in which some ore has been deposited. The limestone lowland and the white quartzite of Ramsey Mountain are abruptly terminated at the south by the older Cambrian shales and arkosic sandstones, which have been thrust westward about 2 miles along an east-west fault, the trace of which lies close to the main road from the gap south of Ramsey Mountain to Basic City.

Because of the favorable structure just described it is recommended that the triangular valley of about 1 square mile lying north of the fault and extending from Ramsey Mountain to Bear Mountain, with its two northward synclinal prongs, be thoroughly prospected by drilling or test pits to determine the presence of manganese. The small synclinal valleys west and southwest of Bear Mountain are also recommended as possibly containing workable deposits and worthy of examination. The small syncline on Sawmill Run is likewise favorable, but large deposits are not to be expected there.

TRACT 5.

Tract 5 lies 6 miles due south of Luray and just northeast of Marksville. (See fig. 32.) As it is a limestone valley inclosed by quartzite ridges it may prove worthy of careful prospecting. The main quartzite ridge of the mountain front is broken down east of the village of Stony Man (Blosserville), as the white Erwin quartzite is here crushed by faulting. South of Stony Man the ridge appears to be anticlinal, with a fault on its southeast side, and farther southwest, west of Ida, there are two quartzite ridges, the outer one apparently anticlinal, so that the valley between them is a syncline. The fault east of the quartzite cuts out the Hampton shale to the southwest, bringing the Unicoi sandstone and Erwin quartzite together. These are minor structural features, however, and even if the synclines in the white quartzite inclose limestone, as is suggested by exposures of certain residual clays, they are hardly to be regarded as favorable for the accumulation of large manganese deposits.

Northeast of Marksville an outlying quartzite ridge trends northeast, and although large masses of rock cover its surface no rock was observed in place, and the structure could not be determined. It is believed to be an anticline, however, but may be faulted on the west side. The valley between the outlying ridge and the main ridge of the mountain front is deeply covered with sandstone wash, and the bedrock is concealed, but with the quartzite fragments there is much iron-ore float and some ferruginous chert derived from limestone. This valley is therefore believed to be a synclinal limestone valley between two quartzite ridges and thus to be structurally favorable for the accumulation of manganese ore. Manganese ore has not been mined in this area, but in a small synclinal valley on the mountain side 2 miles southwest of Marksville some old workings show fragments of manganese oxide, and preparations are being made to reopen the workings.

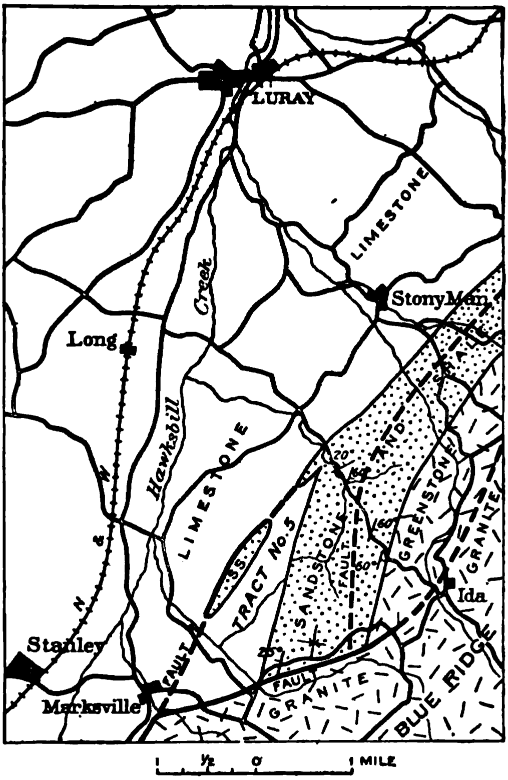

FIGURE 32.—Sketch geologic map of area south of Luray, Va., showing location of tract 5.

The limestone embayment opens into the main valley both at the north and south, but as a fault probably breaks the limestone at these places the bedding is not continuous across these breaks and the syncline is cut off. The synclinal basin therefore forms a wedge-shaped area with the point at the northeast, over 2 miles long and a mile in width at its southwest base. At the southwest it is cut off by pre-Cambrian granite, which is faulted across the end of the basin. The granite has been moved westward along the east-west fracture and now abuts against the ends of first the pre-Cambrian greenstone beds southwest of Ida, then successively the basal Cambrian sandstones and shales (Unicoi and Hampton), the upper white quartzite (Erwin), and finally the limestone of the inclosed valley. The fault thus caused a horizontal displacement of the rocks of at least 3 miles at this place.

This wedge-shaped embayment is regarded as a desirable place to prospect for manganese deposits, as its structure is favorable for the concentration of any manganese that may have been originally present in the surrounding rocks. The portion of the embayment south of the stream and road is a lowland with little coarse wash and has apparently been recently scoured by the stream, so that if ore were originally deposited there it has probably been removed by erosion. The higher part of the area, north of the road, is deeply covered with wash and is more favorable for the occurrence of ore, particularly that portion which lies at or near the saddle in the valley between the outer ridge and the main ridge.

TRACT 6.

Tract 6 is a small area of valley and mountain slope in the vicinity of the Seibel manganese mine, near Happy Creek station on the Southern Railway, 3 miles east of Front Royal. (See fig. 33.) This tract is worthy of careful prospecting for manganese, which can be done most readily with the drill. The rocks of this area are unusually well exposed in the Southern Railway cuts east of the mine. Here the pre-Cambrian greenstone is succeeded on the west by nearly vertical beds of arkosic gray and purple banded sandstone and conglomerate which represent the basal formation (Unicoi sandstone) of the Cambrian. These beds are followed by purple shaly arkosic beds, hackly sandy shales, and soft buff sandstones with low dips and minor folds, and these in turn by nearly vertical, thicker, harder argillaceous sandstone with some thin dark shale partings which represent the Hampton shale. Then follows the main ridge-making upper white quartzite (Erwin), which is nearly vertical but also somewhat folded and much brecciated, the fragments being cemented in part by limonite.

At the foot of the west slope of the mountain is the Seibel manganese mine, described in detail by Hewett.[1] The manganese and manganiferous iron in a new pit at the mine clearly occur in clay that in part retains the original bedding of the limestone from which it was derived and incloses decomposed chert from the limestone. This clay is residual from the Shady dolomite at the base of the Shenandoah group of limestones, for purple shale, residual banded clay, and thin sandstone of the next overlying formation (Watauga shale) crop out near the wagon road west of the mine. In the mine pits the residual clay merges at the top with mottled clay that has moved somewhat down the slope and has been more or less mixed with the sandstone wash from the mountain. The overburden is not more than 10 feet thick at the mine. The ore seems to be mostly deposited in the undisturbed residual clay.

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[1] Hewett, D. F., op. cit., pp. 67–69.

At the west end of the railway cut there is a small detached mass of brecciated white quartzite, which evidently forms a small anticline on the west flank of the main quartzite mass, although it is so highly brecciated that the anticlinal structure can not be determined in the railway cut. The small ridge which this quartzite mass makes on the flank of the main quartzite ridge west of the railway is covered with fragments of the quartzite, but there are no bedrock outcrops on it. It declines toward the southwest and merges into the wash-covered terraced mountain slope on which the Seibel mine is located. In the swale between the main ridge and this small ridge is much iron-ore float and several shallow pits which show considerable manganese oxide. This swale is on the axis of a small syncline that plunges southwestward toward the Seibel mine and incloses the residual clays of the basal limestone beds which rest on the top of the gently dipping white quartzite. Its structure is therefore favorable for the accumulation of manganese ore. The fold, however, is so small that the embayment can not be regarded as likely to furnish a large quantity of manganese and would not be classed as favorable for prospecting if it were not for the good showing of ore at the surface and in the surface pits over a considerable area northeast of the Seibel mine.

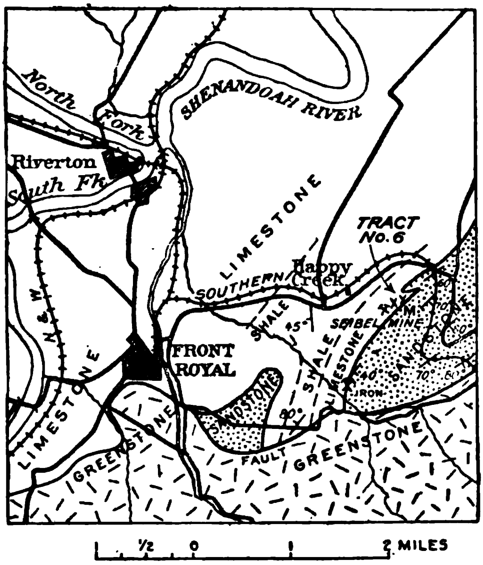

FIGURE 33.—Sketch geologic map of area east of Front Royal, Va., showing location of tract 6.

An iron mine was formerly worked by the Seibel Co. 1 mile southwest of the manganese mine, on the flank of the same ridge. In the mine pit the brecciated white quartzite clearly overlies banded yellow clay residual from the Shady dolomite, which dips 40° SE., so that the beds are overturned. The unaltered Shady dolomite was encountered in a tunnel below the pit. These rocks strike southwestward but are cut off in this direction by the pre-Cambrian greenstone, which is faulted across the ends of the beds. The greenstone has been moved westward along the fault, resting against the ends first of the basal Cambrian beds, then in turn the white quartzite, the residual clay of the Shady dolomite, and lastly purple shales and thin sandstone of the Watauga formation. The horizontal movement of the greenstone was at least 2 miles. To the west the brecciated quartzite makes another low hill 1 mile from Front Royal, which is believed to be a crushed anticline, although the rock outcrops do not fully indicate the structure. The limestone lowland between this sandstone hill and the Seibel iron mine is therefore synclinal. However, on account of the crushing of the quartzite, the marked overturning of the fold at the iron mine, and the probability of minor faulting, this larger syncline is not regarded as particularly favorable for the occurrence of large deposits of manganese ore, although the residual clay is stained in places by manganese oxide.

The most favorable place for prospecting with the drill in this area, therefore, is along the mountain front in the vicinity of the Seibel mine, particularly northeast of the mine, between it and the railway, and search there for commercial deposits is recommended.

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(SHORT PAPERS AND PRELIMINARY REPORTS)

1917

PART II.—MINERAL FUELS

DAVID WHITE
GEOLOGIST IN CHARGE

WASHINGTON
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NOTE.—The Survey's annual volumes entitled "Contributions to economic geology" are issued in parts, and the last part will include a volume title-page, table of contents, and index for the use of those who may wish to bind the separate parts. A small edition of the bound volume will also be issued, but copies can not be supplied to those who have received all the parts.

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CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1917.

PART II. MINERAL FUELS.

DAVID WHITE, *Geologist in charge.*

INTRODUCTION.

The Survey's "Contributions to economic geology" have been published annually since 1902. In 1906 the increase in the number of papers coming under this classification made it necessary to divide the contributions into two parts, one including papers on metals and nonmetals except fuels and the other including papers on mineral fuels. In 1915 the year included in the title was changed from the year in which the field work reported in these papers was done to the year of publication, and in consequence there was no volume entitled "Contributions to economic geology, 1914." The subjoined table gives a summary of these bulletins.

United States Geological Survey "Contributions to economic geology."

Date in title.	Date of publication.[a]	Bulletin No.
1902	1903	213
1903	1904	225
1904	1905	260
1905	1906	285
1906, Part I	1907	315
Part II	1907	316
1907, Part I	1908	340
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1908, Part I	1909	380
Part II	1910	381
1909, Part I	1910	430
Part II	1911	431
1910, Part I	1911	470
Part II	1912	471
1911, Part I	1913	530
Part II	1913	531
1912, Part I	1914	540
Part II	1914	541
1913, Part I	1915	580
Part II	1915	581
1915, Part I	1916	620
Part II	1916	621
1916, Part I	1917	640
Part II	1917	641
1917, Part I	1918	660
Part II	1918	661

[a] The date given is that of the complete volume: beginning with Bulletin 285 the papers have been issued as advance chapters as soon as they were ready.

As the subtitle indicates, the papers included in these volumes are of two classes—(1) short papers giving comparatively detailed descriptions of occurrences that have economic interest but are not of sufficient importance to warrant a more extended description; (2) preliminary reports on economic investigations the results of which are to be published later in more detailed form. These papers are such only as have a direct economic bearing, all topics of purely scientific interest being excluded.

Brief abstracts of the publications of the year are given in the annual report of the Director. The complete list of Survey publications affords, by means of finding lists of subjects and of authors, further aid in ascertaining the extent of the Survey's work in economic geology.

The reports on work in Alaska have been printed in a separate series since 1904, the volumes so far issued being Bulletins 259, 284, 314, 345, 379, 442, 480, 520, 542, 592, 622, 642, and 662.

THE CLEVELAND GAS FIELD, CUYAHOGA COUNTY, OHIO, WITH A STUDY OF ROCK PRESSURE.

By G. SHERBURNE ROGERS.

INTRODUCTION.

Ohio has long been a large producer of natural gas, but the commercial exploitation of the gas resources of Cuyahoga County, in the northeastern part of the State, is comparatively recent. The development of the Cleveland field began early in 1912 with the completion of several successful wells in the western part of the city of Cleveland. Within four years more than 900 wells, most of which were successful, had been completed in an area of about 25 square miles. The excessively close drilling in many parts of this area has resulted in a rapid decline of the output of individual wells, and the older part of the field is destined to be short lived. The field is of interest because of its immediate proximity to a great manufacturing city that has long been a consumer of large quantities of natural gas, and the uneconomic character of its development is thus especially unfortunate.

Most of the wells in the Cleveland field draw their supplies from the so-called Clinton sand, which is a productive reservoir of gas in a belt extending from north to south through the east-central part of the State. (See index map, Pl. I.) Although no evidence has yet been found to show that the Cleveland field is directly connected with these fields, it is at the northern extremity of the same structural belt and is therefore related to them geologically. During the later half of 1915 the Cleveland field was extended somewhat to the southwest, and prospecting is now most active in that direction. A small pool has been developed just south of Berea, which lies 14 miles southwest of Cleveland, and further extensions in that direction would serve to connect the Cleveland field with the belt of fields to the south.

The writer spent half of July, 1915, and a week in June, 1916, examining the Cleveland field. As the field was already largely developed, it was not deemed advisable to study the structure in great detail; the exact altitudes of the wells were therefore not determined by actual survey, but were measured by an aneroid barometer or were simply estimated from the Geological Survey's topographic maps of the Berea and Cleveland quadrangles, with a probable range in accuracy of 5 to 20 feet. No attempt was made to map or study the rocks that crop out at the surface, as an examination of their structure would not show with accuracy the attitude of the Clinton sand below.

The writer takes pleasure in acknowledging his indebtedness to Mr. R. W. Gallagher, Mr. E. M. Werner, and other officials of the East Ohio Gas Co., who furnished the logs of many wells and information concerning the location, date of completion, and initial rock pressure and open flow of most of the wells in the field. Special thanks are also due to Mr. S. S. Wyer, of Columbus, Ohio, for data of a similar kind; and to Mr. C. J. Weideman, of the Rocky River Development Co.; Mr. S. S. Hulse, of Cleveland; the Berea Pipeline Co.; the Rushville Drilling Co.; and many other companies and persons for well logs and general information.

HISTORY AND DEVELOPMENT.

In 1885, or soon after the famous discovery of gas at Findlay, Ohio, a well was sunk to a depth of 3,000 feet in Newburg, just southeast of Cleveland. Only a small flow of gas was encountered, but the discovery of salt in this well may be regarded as the beginning of the salt industry in northeastern Ohio. One or two other wells drilled in Cuyahoga County in the next few years were unsuccessful in finding gas or oil, and the territory was not regarded as promising. Between 1900 and 1910 prospecting became more active, especially in the western part of the county, but none of the wells found commercial flows of gas.[1]

In the early part of 1912, however, four good wells were completed in the Clinton sand at the plants of the Winton Motor Car Co. and the National Carbon Co., near the western limits of the city of Cleveland. Other manufacturing firms began drilling shortly after, and during 1912 and 1913 about 40 wells were completed, 27 of which were successful. Most of the successful wells were drilled on factory sites within or close to the city limits; it is rather curious that most of the wells drilled farther west, near what has since proved to be highly productive territory, happened to be located in small barren areas and were dry.

The general success of the earlier developments near the city attracted widespread attention, and late in 1913 drilling activity became very pronounced. During 1914 some 300 wells were completed in the westerly suburbs of Cleveland known as Lakewood and West Park. Most of the drilling was done by individuals or small companies controlling one or more suburban lots, and consequently the wells in many localities were closely crowded together. In some places wells were sunk within 100 feet of one another on lots scarcely large enough to accommodate the drilling rig. The fairly uniform distribution of the gas, the regularity of the strata, and the general absence of water except at certain well-defined horizons, making drilling comparatively simple, together with the proximity of the field of operations to a great center of supplies and the low cost of hauling over paved roads and streets, all combined to reduce the cost of drilling and to make the investment attractive and apparently sound. The rapid decline of the earlier wells was not taken seriously and seemed to act as a stimulus to further drilling rather than as a deterrent.

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[1] In the Cleveland field a well having an initial daily open flow of less than 250,000 cubic feet is generally considered dry, and this usage is followed in the present report.

The areas first drilled were those nearest to the west line of the city. Near the shore of Lake Erie the development started within the city limits and extended rapidly as far west as Giel Avenue. Most of the drilling west of this locality has been more recent, and the wells are not as closely crowded. Another center of the westerly development is on the west line of the city between Lorain Avenue and the Lake Shore & Michigan Southern Railway tracks. In this locality the wells are very closely spaced, one tract of about 70 acres containing 37 wells. From this district the development extended toward the west, chiefly in the area between Lorain and Madison avenues. Most of the land in this area had not been subdivided into lots, and the wells are not as closely crowded as near the city limits. In the early part of 1915 a number of excellent wells were completed just west of Rocky River, and since then a narrow strip of productive territory extending 4 miles westward along Center Ridge Road has been outlined. During the same period development extended south of Lorain Avenue, and a number of successful wells were drilled in a belt extending on both sides of the Lake Shore & Michigan Southern Railway tracks nearly to the south border of West Park Township. Late in 1915 the prolific Brook Park pool, lying partly in West Park and partly in Middleburg Township, was developed, and this pool seems to be now well outlined.

The great majority of the wells throughout the area described have had an initial production in excess of half a million cubic feet daily each, and a great many produced initially between 3,000,000 and 10,000,000 cubic feet. Few of the wells are long-lived, however, and at the present time about two-fifths of the successful wells have been abandoned. As the life of a gas well depends largely on the size of the territory that it drains, the decline in the older and thickly drilled portions of the field has been especially rapid, and the life of the average well has probably not been more than 12 months. The wells in the western and southern parts of the field are less closely spaced; few of them have yet been abandoned and it is probable that their average life will be considerably over two years.

Within the city limits the development of the Clinton sand has been restricted chiefly to the area lying north of Lorain Avenue and west of West Boulevard, which forms the eastern edge of the districts described above. There are a few wells south of the city line, in the area between Linndale and Brooklyn, and several of these report a small production of oil.

Most of the wells within the city obtain gas from the so-called Newburg sand, which is higher than the Clinton. Several wells finished in this sand during 1913 gave only small flows, but in February, 1914, a well credited with an initial flow of 12,500,000 cubic feet was completed at the Stadler Rendering & Fertilizing Co.'s plant, on Cuyahoga River just north of the mouth of Big Creek. In March two other good wells were brought in, and within six months 68 wells had been drilled in the immediate vicinity. During the summer of 1915 another pool was developed in the Newburg sand near the intersection of Walworth Avenue and West Twenty-fifth Street, about 2 miles north of the pool first discovered.

A number of wells have been drilled at various times along the east bank of Cuyahoga River and most of them have found small supplies of gas in the Newburg sand. A few wells have also been drilled in the eastern part of the city, but none of them found commercial supplies of gas, and Cuyahoga River may therefore be regarded as the general eastern limit of the Cleveland field at the present time.

STRATIGRAPHY.

GENERAL SECTION.

The rocks that crop out in the Cleveland field are of Mississippian and late Devonian age, but those penetrated by the drill include formations down to the Ordovician. For the information of those not familiar with the geologic section of this part of Ohio, and for convenience in interpreting the well logs of this field, the following table of formations is given. The thicknesses of the upper formations have been taken from published reports on the geology of this region; those of the lower formations are derived from a study of logs of wells in the immediate field.

Generalized section of rocks in the Cleveland gas field, Ohio.

System.	Group or formation.		Thickness in feet.	Character.	Driller's description.
Quaternary (Pleistocene series).	Glacial drift.		10-400	Boulders, pebbles, sand, and clay.	Drift.
Carboniferous (Mississippian series).	Berea sandstone.		40-150	Medium to coarse grained white, buff, or brown sandstone.	Berea grit.
Devonian or Carboniferous.	Bedford shale.		60-80	Bluish-gray to reddish shale, with some thin layers of limestone.	Ohio shale, 1,100-1,400 feet.
Devonian.	Ohio shale group.	Cleveland shale.	50-120	Massive hard black bituminous shale with a few bluish layers in lower portion.	
		Chagrin shale.	850-1,200	Soft bluish-gray clay shale, with some concretionary layers.	
		Huron shale		Black and bluish shale in upper and lower portions, with a band of gray shale near middle.	
	Olentangy (?) shale.		80	Gray calcareous shale.	
	Delaware limestone.		500-700	Blue and gray limestone, becoming dolomitic in lower part. Contains a 30 to 50 foot bed of white quartz sandstone 350 to 450 feet below top.	Big lime [includes Newburg sand and some "stray" sands in lower 300 feet], 1,425-1,825 feet.
	Columbus limestone.				
Unconformity Silurian.	Monroe formation.				
	Salina formation.		400-600	Shale, dolomite, anhydrite or gypsum, and rock salt.	
	Niagara limestone.		400-600	Dolomite and limestone.	
	"Clinton" formation.		150-250	Calcareous shale and thin-bedded limestone, with sandstone layer in lower part.	[Includes Little lime], 75-150 feet.
					Clinton sand, 0-60 feet.
					25-75 feet.
	"Medina" shale.		300-400	Red clay shale with thin layers of sandstone.	Medina red rock.
Ordovician.	Shale and limestone of Cincinnatian age.		1,100-1,250	Dark shale with thin layers of limestone, especially in upper part.	Slate and shells.
	Trenton (?) limestone.		(?)	Limestone.	Trenton lime.

A mantle of glacial drift of variable thickness overlies the Carboniferous and older rocks in the area here described. Practically all the wells start in the Chagrin or the Cleveland shale, and only two of them penetrate far below the "Clinton" formation. The Chagrin, Cleveland, and Bedford shales are well exposed in the vicinity of Cleveland, but the Berea sandstone has been removed by erosion from this locality and does not extend far north of the town of Berea. The rocks exposed at the surface dip very gently to the south or southwest, but the Clinton sand dips to the east.

WELL LOGS.

In order to show in more detail the character and thickness of the formations in the Cleveland field the following well logs, together with their geologic interpretation, are given. The log of the deep well of the Park Drop Forge Co. furnishes a detailed record of the formations down to the Trenton (?). The second log, which is typical of most of those in the field, shows the "Clinton" formation in particular detail. The third and fourth logs give the position of the Newburg sand and the character of the Big lime. The fifth shows the total thickness of the shale formations between the Berea sandstone and the Big lime, and the sixth is included to show in detail the character of these formations.

Logs of wells in Cleveland gas field.

Park Drop Forge Co.'s well, East Seventy-ninth Street and New York Central Railroad tracks, Cleveland.

Driller's description.	Thickness.	Depth.	Equivalent formation.	Thickness.
	Feet.	*Feet.*		*Feet.*
Sand and blue clay	100	100	Glacial drift	401
Blue clay and quicksand (water at 148 feet).	110	210		
Blue clay (water at 230 feet)	45	255		
Gravel and fire clay	30	285		
Fire clay	25	310		
Fire clay and gravel	65	375		
Gravel and shale	26	401		
Shale (water at 432 feet)	24	425	Ohio shale group and Olentangy? shale.	604
Blue shale (little gas at 755 feet)	420	845		
Shale	160	1,005		
Lime, very hard	77	1,082	Delaware, Columbus, and upper part of Monroe formations.	320
Lime mixed with sand and salt (salt water at 1,320 feet).	243	1,325		
Lime and sand rock, some water	35	1,360	Sandstone member of Monroe formation.	35
Lime, very hard	35	1,395	Lower part of Monroe formation and upper part of Salina formation.	425
Lime mixed with sand (salt water at 1,420 feet).	33	1,428		
Blue lime, hard, some water	17	1,445		
Lime mixed with sand	28	1,473		
Hard blue lime	20	1,493		
Blue and gray lime	127	1,620		
Lime, hard	4	1,624		
Limestone	106	1,730		
Lime with slate streaks	55	1,785		
Salt and lime (pure salt at 1,850 feet)	73	1,858	Middle part of Salina formation	220
Salt streaked with lime	147	2,005		

Logs of wells in Cleveland gas field—Continued.

Park Drop Forge Co.'s well, East Seventy-ninth Street and New York Central Railroad tracks, Cleveland—Continued.

Driller's description.	Thickness.	Depth.	Equivalent formation.	Thickness.
	Feet.	*Feet.*		*Feet.*
Slate and lime	25	2,030	Lower part of Salina formation and Niagara limestone.	730
Lime	75	2,105		
Slate and lime	121	2,226		
Hard lime	209	2,435		
Lime and sandstone (water at 2,656 feet).	245	2,680		
Sandstone	18	2,698		
Limestone	37	2,735		
Gray slate and lime shells	65	2,800	"Clinton" formation	235
Sand rock	30	2,830		
Clinton sand	38	2,868		
Sand and slate	50	2,918		
Slate and shells	52	2,970		
Medina red rock	130	3,100	"Medina" shale	395
Medina red rock and shells	265	3,365		
Gray slate and lime shells	83	3,448	Limestone and shale of Upper Ordovician (Cincinnatian) age.	1,117
Gray slate	97	3,545		
Slate and lime shells	105	3,650		
Slate	115	3,765		
Slate and lime shells	140	3,905		
Slate	70	3,975		
Brown slate	56	4,031		
Slate with lime shells	451	4,482		
Trenton sand and rock	54+	4,536	Trenton (?) limestone	54+

Sophia Schupp well No. 1 (well 59, fig. 2).

[Completed April 6, 1915.]

Driller's description.	Thickness.	Depth.	Equivalent formation.	Thickness.
Gravel	82	82	Alluvium	82
Shale	938	1,020	Ohio shale group and Olentangy(?) shale.	938
Limestone, carrying water at 1,284, 1,314, 2,212, and 2,390 feet.	1,415	2,435	Delaware, Columbus, Monroe, Salina, and Niagara formations.	1,415
Shale	57	2,492	"Clinton" formation	198
Limestone	41	2,533		
Shale	16	2,549		
Clinton sand	16	2,565		
Shale	10	2,575		
White sand	10	2,585		
Shale	48	2,633		

National Carbon Co.'s well No. 2, Berea Road and West One hundred and Seventeenth Street.

[Completed February, 1912.]

Driller's description.	Thickness.	Depth.	Equivalent formation.	Thickness.
Drift	25	25	Glacial drift	25
Shale	1,156	1,181	Ohio shale group and Olentangy(?) shale.	1,156
Limestone, carrying water at 1,420 feet	559	1,740	Delaware and Columbus limestones, Monroe and probably part of Salina formations.	559
Salt	25	1,765	Salina formation (middle part)	290
Limestone	70	1,835		
Salt	20	1,855		
Limestone	140	1,995		
Salt	15	2,010		
Limestone	10	2,020		
Salt	10	2,030		
Limestone, carrying water at 2,530 feet	570	2,600	Niagara limestone and probably lower part of Salina formation.	570
Shale	83	2,683	"Clinton" formation	134+
Limestone (Little lime)	29	2,712		
Shale	9	2,721		
Clinton sand	13+	2,734		

Logs of wells in Cleveland gas field—Continued.

Barkwell Brick Co.'s well No. 1, Cleveland.

Driller's description.	Thickness.	Depth.	Equivalent formation.	Thickness.
	Feet.	*Feet.*		*Feet.*
Shale	1,190	1,190	Ohio shale group and Olentangy (?) shale.	1,190
Limestone, carrying water at 1,500 feet	1,280	2,470	Delaware, Columbus, Monroe, Salina, and part of Niagara formations.	1,280
Newburg sand	15	2,485	Lower part of Niagara limestone	250
Limestone, carrying water at 2,665 feet	235	2,720		
Blue slate	15	2,735	"Clinton" formation	160+
Red rock	25	2,760		
Limestone (Little lime)	17	2,777		
Slate and shells	49	2,826		
Clinton sand:				
Gray sand	6	2,832		
Red sand	18	2,850		
Pink sand	6	2,856		
White sand	6	2,862		
White slate	6	2,868		
Broken sand and slate	6	2,874		
Slate and shells	6+	2,880		

Well near fair grounds, Berea.

Gravel and sand	10	10	Glacial drift	10
Berea sand	82	92	Berea sandstone	82
Shale	1,228	1,320	Bedford shale, Ohio shale group, and Olentangy (?) shale.	1,228
Big lime, carrying water at 1,630, 2,492, and 2,570 feet.	1,410	2,730	Delaware, Columbus, Monroe, Salina, and Niagara formations.	1,410
Shale	31	2,761	"Clinton" formation	193
Little lime	19	2,780		
Shale	51	2,831		
Clinton sand	24	2,855		
Shale and sand	68	2,923		
Medina red rock	7+	2,930	"Medina" formation	7+

Wade well, corner of Euclid and Case avenues, Cleveland.[a]

Drift beds	300	300	Glacial drift	300
Blue shale	10	310	Chagrin and Huron shales	550
Black shale	40	350		
Dark shale	25	375		
Dark shale (somewhat lighter)	40	415		
Gray shale	30	445		
Black shale	10	455		
Gray shale	185	640		
Black shale (containing *Sporangites*)	15	655		
Gray shale	60	715		
Black shale (*Sporangites* abundant)	15	730		
Gray shale	65	795		
Black shale	55	850		
Gray shale, calcareous	80	930	Olentangy ? shale	80
Limestone	117	1,047	Delaware and Columbus limestones	117

[a] Orton, Edward, The Ohio shale as a source of oil and gas in Ohio: Ohio Geol. Survey Rept., vol. 6, p. 429, 1888.

SUBDIVISIONS.

The foregoing well logs taken together furnish a fairly detailed section of the rocks underlying the Cleveland field. In most well records, however, only the major lithologic units are distinguished, and the following brief description of the several formations is therefore based on the divisions commonly recognized by the driller.

Ordovician rocks.—Only two wells in the Cleveland district have penetrated far into the Ordovician rocks—the Park Drop Forge Co.'s well, the log of which is given above, and the Cleveland Twist Drill Co.'s well, which is in the same part of the city. The log of the Drill Co.'s well shows 1,265 feet of the shale and shells between the "Medina" and the Trenton (?), as against 1,117 feet in the Forge Co.'s well. So far as known the limestone called Trenton in these logs was so named merely on the basis of its general character and position, and this discrepancy suggests that the identification in one or both logs may be erroneous. Both logs agree in reporting the so-called Trenton as barren of gas. Whether or not the true Trenton was reached the great depth at which this formation lies in the Cleveland field places it outside of the range of ordinary drilling.

"*Medina red rock.*"—Next above the Ordovician shales and limestones is the Medina red rock of the drillers. This formation, as described in the logs, consists chiefly of soft bright-red shale with interbedded layers of gray or red sandstone. A number of wells that fail to find a gas-bearing stratum in the overlying "Clinton" formation extend a few feet into the upper part of the "Medina," but only three wells penetrated the whole formation. The logs of the two deep wells referred to above, both in the northeastern part of Cleveland, show thicknesses of 295 and 356 feet, and that of the Gray well, 2 miles northwest of Berea, shows a thickness of 345 feet.[1]

"*Clinton*" *formation.*—The character of the so-called "Clinton" formation is well shown by several of the logs given above and by the sections on page 18. It is made up largely of shale, probably calcareous, but contains several thin beds of hard limestone, and in most localities one or more layers of sandstone. One of these layers, which generally occurs 35 to 50 feet above the top of the "Medina," is the well-known Clinton sand of the drillers. It is a gray to red quartz sandstone, which in some localities contains lenses of shaly material and in others is "broken" by harder impervious layers. "Stray" sands are occasionally reported above the Clinton, and in the southern part of the field a layer of red sand appears to underlie it. The limestone layers above the Clinton sand are generally thin and hard and are reported by the driller as shells, but in some logs one of them is distinguished as the Little lime. Most of the "Clinton" formation is gray, but some of the beds have a pink or red tinge. The total thickness of the formation is variable, but generally ranges between 150 and 200 feet.

The "Clinton" formation crops out in west-central Ohio, but a short distance west of the Cleveland field the Clinton sand itself feathers out and is known only from well records.

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[1] Prosser, C. S., The Devonian and Mississippian formations of northeastern Ohio: Ohio Geol. Survey, 4th ser., Bull. 15, p. 480, 1912.

When gas was first discovered in these rocks at Lancaster the formation was thought to be the equivalent of the Clinton formation of New York. Later studies have shown that the beds lie below the true Clinton and probably belong to the Medina group. As the term "Clinton" sand is now too well established among the drillers to be supplanted, and as no other name for the formation that contains this sand has yet been generally accepted, the term "Clinton" formation is retained in this paper in conformity with current usage.

Big lime.—The Big lime consists of a series of limestone, dolomite, salt, and gypsum beds, which, in the Cleveland field, aggregate from 1,425 to 1,825 feet in thickness. The upper and lower parts of this series consist chiefly of limestone and dolomite; the middle part contains the salt and gypsum.

The lower portion of the Big lime consists of hard light-gray magnesian limestone, or dolomite, averaging about 500 feet in thickness. Most of it is of Niagara age, but some of the upper beds probably belong to the Salina formation. About 200 feet above the base of the Niagara is the so-called Newburg sand, which is not a true sand but merely a porous layer in the ordinarily massive dolomite. The "stray" sands occasionally reported as occurring in these strata are probably of similar character. In most of the wells salt water is encountered at about 75 feet above the base of the Niagara and also at 200 to 300 feet above the base.

The middle portion of the Big lime, which consists of limestone, salt, and gypsum or anhydrite, is essentially the same as the Salina formation. The upper and lower portions of the Salina as recorded by drillers can not be distinguished from the underlying and overlying limestones, and as the thickness and distribution of the salt beds are irregular that part of the Salina that can be identified in well records is variable in thickness. From one to four beds of salt are generally reported by the driller, and in some localities the total thickness of salt may reach 125 feet.

The upper portion of the Big lime ranges between 500 and 700 feet in thickness and includes the Monroe formation and the Columbus and Delaware limestones. In many well records this series of strata is not subdivided, but detailed logs record a sandstone layer between 350 and 450 feet below the top. This sandstone, which occurs in the Monroe formation and is generally called the Sylvania sandstone, has been identified at a number of points in northeastern Ohio.[1] In a few localities it is known to carry small amounts of oil or gas, and in other places shows of gas have been reported from the upper part of the Big lime at about this horizon, but the sandstone has not proved to be as productive a reservoir as was once thought.[1] The sandstone is overlain by the massive dolomite strata composing the upper part of the Monroe, above which is a thinner-bedded limestone that is known in Ohio as the Columbus but is believed to be the equivalent of the Onondaga limestone of New York. Overlying the Columbus and forming the top of the Big lime is the Delaware limestone, a rather thin-bedded formation which generally can not be distinguished in well records from the Columbus. Salt water is usually encountered at one or two horizons in the upper part of the Big lime, and some wells report water at about the horizon of the sandstone of the Monroe formation.

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[1] Prosser, C. S., op. cit.

Ohio shale of drillers.—The Big lime is overlain by a considerable thickness of dark-blue or black shale, which is known to the driller as the Ohio shale. In most well records the individual strata are not distinguished, but in the log of the Wade well given on page 8 the beds are described in detail. This shale occupies the entire interval between the Delaware limestone and the Berea sandstone, and in the Cleveland field it ranges in thickness from 1,100 to 1,400 feet. Most of the wells start below the top of the shale, however, and pass through only about 1,100 feet before reaching the Big lime.

The lowest formation of this shale series is probably the Olentangy shale, which is characteristically gray and calcareous. It is easily recognized in the central part of the State, but its identification in the Cleveland district rests chiefly on the record of the Wade well, which shows 80 feet of gray shale at about the horizon of the Olentangy. The Olentangy if present is overlain by the Ohio shale group, which consists of the Huron, Chagrin, and Cleveland shales. These formations can be differentiated at the outcrop, but in most well records they are indistinguishable. The upper part of the Chagrin shale is exposed in the cliffs along the lake shore at Cleveland, and the Cleveland shale is well exposed in the banks of Rocky River at the western edge of the field. The Ohio shale group is overlain by the reddish Bedford shale, which crops out in Big Creek and also near Berea and which is above the horizon where most of the wells start.

Berea sandstone.—The Berea sandstone is a remarkably persistent formation, averaging about 75 feet in thickness, and is one of the best and most widely known horizon markers in Ohio. It crops out at the town of Berea, where it is extensively quarried. As it is not present in the main Cleveland field it is recorded only in the logs of a few wells near Berea.

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[1] Neff, Peter, The Sylvania sandstone in Cuyahoga County, Ohio: Geol. Soc. America Bull., vol. 1, pp. 81–83, 1889.

CHANGES IN THICKNESS.

Most of the formations underlying the Cleveland field are not constant in thickness, and some of them, as indicated in the table on page 5, change considerably from place to place. In some of the formations the variation in thickness is irregular, but in others a fairly regular change in one direction or another may be observed. The net result of these changes is a marked eastward thickening of the formations overlying the Clinton sand. This condition is economically important, for it means that wells drilled at points east of Cleveland must penetrate a considerably greater thickness of rock before reaching the Clinton sand.

Throughout the Cleveland field and for some distance to the east the Berea sandstone and Bedford shale maintain a fairly constant combined thickness. The Cleveland shale becomes thinner toward the east, being over 90 feet thick on Rocky River, at the western edge of the field, about 55 feet on Doan Brook, near the eastern edge, and only 17 feet near Painesville, in Concord Township, Lake County, about 27 miles farther east.[1] This decrease, however, is more than compensated by the increase in thickness of the underlying Chagrin and Huron shales, which amounts to over 600 feet in the same distance and which continues at about the same rate as far east as the State line. The thickness of the limestone formations constituting the upper part of the Big lime appears to be fairly constant as far east as Painesville, but east of that locality the Monroe formation decreases greatly in thickness. The Salina formation, on the other hand, is believed to thin markedly to the west of Cleveland. It is generally thought to disappear entirely at Elyria, though wells as far west as Oberlin encounter a few thin beds of salt[2] which may belong to this formation. Presumably because of this wedging out of the Salina to the west, the Big lime as a whole is some 400 feet thicker at Cuyahoga River than at Oberlin. It maintains about the same thickness from Cuyahoga River to Painesville, but east of that locality it decreases in thickness, because of the wedging out of the Monroe formation, and near Erie, Pa., it is some 600 feet thinner.[3] The thickness of the shale and limestone beds between the base of the Big lime and the top of the Clinton sand is fairly constant over a considerable area, though locally it varies considerably.

These variations in thickness are shown in generalized form in figure 1. The variation in a distance of 13 miles across the Cleveland field, as deduced from a number of well logs, is shown on the correct horizontal scale, and in order to extend the comparison beyond the

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[1] Prosser, C. S., op. cit., pp. 241, 475.

[2] Hubbard, G. B., Gas and oil wells near Oberlin, Ohio: Econ. Geology, vol. 8, p. 685, 1913.

[3] Prosser, C. S., op. cit., pp. 411–421.

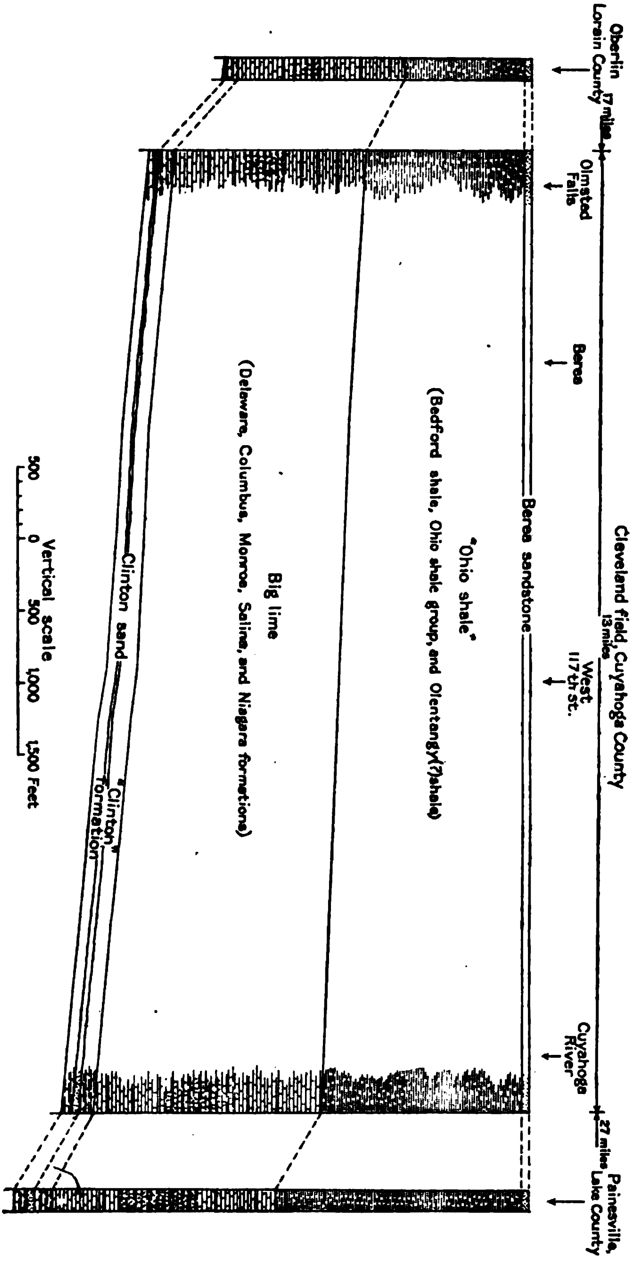

FIGURE 1.—Geologic section from Oberlin through Cleveland to Painesville, Ohio, showing eastward thickening of subdivisions between Berea sandstone and Clinton sand. Line of section is shown by line A–A on index map in Plate I.

field logs of wells near Oberlin, Lorain County, and near Painesville, Lake County, are added.

At Oberlin the shale formations between the Berea and the Big lime aggregate about 850 feet in thickness. At Olmsted Falls, near the southwest corner of the Cleveland field and about 17 miles east of Oberlin, they are 1,120 feet thick,[1] and near Berea, 4 miles farther east, 1,228 feet. On Cuyahoga River, at the eastern edge of the Cleveland field, they are about 1,425 feet thick.[2] At Painesville, 30 miles east of Cuyahoga River, they aggregate about 1,750 feet, and in the central part of Trumbull County, 35 miles southeast of Painesville, about 2,400 feet.[3] The average thickness of the Big lime at Oberlin is 1,184 feet, at Berea 1,425 feet, and on Cuyahoga River nearly 1,600 feet. The log of the Park Drop Forge Co.'s well, in the eastern part of Cleveland, shows a thickness of over 1,700 feet, but this may be only a local thickening. Near Painesville the Big lime is 1,580 feet thick, and its maximum thickness is therefore probably reached in the district between Cuyahoga River and Painesville.

To sum up these variations, the shale formations increase markedly in thickness from Oberlin to the State line, whereas the Big lime increases only as far east as Lake County, beyond which it decreases. The interval between the Berea and the Clinton sand is about 2,100 feet at Oberlin, 3,100 feet on Cuyahoga River, and 3,400 feet in Lake County and near the State line.

STRUCTURE.

Sedimentary rocks are generally deposited in a nearly horizontal position, but during slow earth movements the strata become more or less disturbed and are caused to incline or dip in one direction or another. The inclination or attitude of the rocks is known as geologic structure. A simple slope is called a monocline, an arch an anticline, and a trough a syncline. Where the structure is gentle, as in northeastern Ohio, it is best represented on a map by structure contours, which are lines connecting all points at which a given bed is the same distance above or below sea level. The structure of the Clinton sand is shown in Plate I by contour lines spaced at an interval of 20 feet, the datum being a plane 3,000 feet below sea level.

It was impracticable to determine the altitude of the wells by spirit level; at most of them an aneroid barometer was used and for some the altitude was merely estimated from the topographic map. For this reason the delineation of the structure on Plate I can not be considered accurate within less than 15 or 20 feet, especially in the northern and eastern parts of the field. This degree of accuracy is probably as great as that of the ordinary well log, however, for steel-line measurements of the depth of the sand have been made only in a few wells, chiefly in Middleburg Township. Moreover, the position of the Clinton sand in the so-called "Clinton" formation is very irregular, and where it is barren of gas its identification by the driller may be open to question. The structure of the Clinton sand as shown in Plate I is probably a combination of the true structure with the stratigraphic irregularity of the sand, but there is no reason to doubt that at least all the major structural features are delineated.

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[1] Prosser, C. S., op. cit., p. 496.
[2] Orton, Edward, op. cit., p. 352.
[3] Prosser, C. S., op. cit., p. 339.

The broader structural relations of the Cleveland field may be seen by reference to the small index map in Plate I, which shows in generalized form the structure of the Clinton sand throughout most of its productive area. The "Clinton" formation on the eastern flank of the Cincinnati anticline crops out in a band extending from north to south across Ohio and dips to the east beneath the great Appalachian coal basin. The Clinton sand does not crop out, however, but feathers out in central Ohio, and the great central gas fields occupy a belt along the thinning edge of the sand. Within this belt the average dip is about 50 feet to the mile and the structure is broadly monoclinal, but there are many minor undulations in the general slope, and in places small though well-defined anticlines have been recognized. In northern Ohio the angle of dip appears to decrease slightly and the direction of strike trends somewhat to the east. In Cuyahoga County the strike changes rather abruptly to the northeast, and in Geauga and Ashtabula counties it appears to be almost due east. Information as to the dip of the sand in this region is very meager, but the structure at Niagara, N. Y.,[1] and in southwestern Ontario[2] suggests that it is 30 or 40 feet to the mile. It should be borne in mind that the position of the Clinton sand with reference to sea level is controlled to a considerable degree by the variation in thickness of the overlying formations, and that because of the eastward thickening of the so-called Ohio shale structure contours on the Berea sandstone would be very different from those on the Clinton. Despite the uncertainty as to the structure of the sand under Lake Erie it is clear that the Cleveland field is located near the point at which the most abrupt change in direction of strike takes place. The field appears to be directly associated with a fairly well defined nose or bulge on the monoclinal slope, directly south of a trough which is presumably due to the buckling of the strata under strains attending the change in strike.

The larger map showing the structure of the field in detail covers approximately the area involved in the nose referred to. The axis of this nose runs eastward through the north-central part of the field, but the structure has somewhat the nature of a terrace and its crest is not well defined. In the southern part of the field near Berea the contours run almost due east, but they trend to the northeast in the eastern part of Middleburg Township and sharply back to the northwest near the shore of Lake Erie. The southeasterly dip near Berea and the northerly dip near the lake shore are pronounced; that in the latter locality is particularly sharp, and marks the edge of the trough in the elbow formed by the general change in strike of the formation. The dip in the main or central part of the field is to the east, and the slope is gentle and comparatively regular from Rocky River to the city line. East of the city line the dip decreases, and in the northeastern part of the city there is a fairly well defined structural terrace, the southern slope of which underlies the district between Brooklyn and Newburg. West of Rocky River the dip is also slightly less than in the main part of the field but is interrupted by a localized nose or undulation which presumably represents the axis of the major structure.

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[1] Kindle, E. M., and Taylor, F. B., U. S. Geol. Survey Geol. Atlas, Niagara folio (No. 190), p. 14, 1915.

[2] Malcolm, Wyatt, Oil and gas fields of Ontario and Quebec: Canada Geol. Survey Mem. 81, pp. 48–53, 1915.

The productive area is confined, in a broad sense, to the middle part of the structural nose, forming a belt extending across its axis and lying mostly between the 1,000-foot and 1,100-foot contours. A narrow strip also extends along the axis to the west at least as far as the 1,220-foot contour. Within these areas the sand varies greatly in productivity, and in some localities is entirely barren; but the variations are apparently unrelated to minor structural features and are governed directly by the lithologic character of the sand itself. Near the lake shore and West One hundred and seventeenth Street the productive portion of the sand extends somewhat below the 1,000-foot contour, but elsewhere the sand below this level seems to be either barren or poor. The 1,000-foot contour is followed in a general way entirely across the field by an irregular belt of wells that find oil. The production of gas from the eastern part of the field, in which the Clinton sand lies below the 1,000-foot contour, is comparatively small and comes almost entirely from the Newburg sand, the detailed structure of which can not be determined.

The structural relations of the pools of the area and the influence of the structure on the accumulation of gas will be discussed below.

GAS RESOURCES.

GAS-BEARING STRATA.

Although the great bulk of the gas produced in the Cleveland field comes from the Clinton sand, some gas has been found in other formations. It occurs at various horizons in the glacial drift, the so-called Ohio shale, the Big lime, and the " Clinton " formation.

The gas occurring in the drift and in the underlying shales is generally known as low-pressure gas, in contradistinction to the high-pressure gas in the lower part of the Big lime and in the "Clinton" formation. Gas has been obtained in the drift by only a few wells, and accumulations in this formation are of negligible economic importance. The shale gas, however, is more widely distributed and has long been an important source of domestic supply. Its vertical distribution in the shale formations seems to be irregular, but most of the wells are successful in finding small supplies at one horizon or another, especially in the district west of the west city line. The initial closed pressure of the gas may exceptionally be several hundred pounds, but after a few days the pressure is generally less than 50 pounds and in some wells is only 5 or 10. The daily open flow is generally less than 20,000 cubic feet, but the wells are comparatively long lived, some of them producing for 20 years or more. Owing to the small capacity of most of the wells, the shale gas is of little use in manufacturing, but its value for domestic purposes is attested by the fact that, according to the records of the Geological Survey, there are about 570 shale-gas wells in Cuyahoga County.

Small accumulations of gas or oil have occasionally been found in the upper part of the Big lime. The largest flow of gas recorded for this rock is 1,009,800 cubic feet, which was found by well 52 (fig. 6) in a "stray" sand 215 feet below the top of the Big lime. Two wells near Hilliard Road and Madison Avenue found shows of oil about 270 feet below the top, but these deposits appear to be of no economic importance.

The lower part of the Big lime contains the Newburg or Stadler sand, which is locally a productive reservoir. This "sand," which in many localities is oily and chocolate-brown in color, is in reality a porous phase of the Niagara limestone occurring about 360 feet above the Clinton sand. It is generally thin; in the logs of several wells that produced initially over 5,000,000 cubic feet it was reported to be less than a foot thick. Its areal distribution is very irregular, and the two principal pools that have been developed in this sand, both near Cuyahoga River, are very small. Owing to the pockety character of the Newburg sand the production of the wells generally falls off rapidly, though high initial pressures and flows are characteristic. In the western part of the field practically all the wells penetrate to the Clinton sand, and the Newburg is rarely reported. Several wells in the Lakewood group (see fig. 8, p. 45) produce from the Newburg, however, and one or two wells in this group report flows of over a million cubic feet from both Newburg and Clinton. Several wells have found shows of oil in the Newburg; one near Bunts Road and Lorain Avenue reported 10 barrels of oil. The material reported as Newburg in the logs of some of the wells in the western part of the field is only 275 to 300 feet above the Clinton and may not be the same as the Newburg of the Cuyahoga River district.

The Clinton sand is at present the most valuable reservoir of gas in Ohio and is the source of over 90 per cent of the gas produced in the Cleveland field. Where productive it is a clean, fine to medium grained, gray to red quartz sand, resembling the Berea in general appearance. Where unproductive it is usually shaly or is "broken" by thin hard shells. In West Park Township the sand is generally gray and consists of a single bed, in which the productive portion is a few feet below the top. In a few wells, however, the gray sand is separated into two benches by a layer of shale, and though either bench or both may be productive the upper is commonly the richer. In the southern part of the field the Clinton generally consists of two sands, the lower of which is red. The red sand yields little gas, and in the district south of the city only one well has found it productive. In this district, however, and as far southwest as Berea a number of wells report oil in the red sand. The character of the Clinton sand and its position in the "Clinton" formation are shown by the logs of the Schupp well and the Barkwell Brick Co.'s well, given above, and in the following sections:

Sections of "Clinton" formation from logs of wells.

Well 1 mile east of Berea, Middleburg Township.

Big lime.	Feet.
Shale	82
Little lime	11
Shale	8
Clinton sand:	
White sand with gas	5
Shaly sand	10
Red sand, with show of oil	12
Slate	35
"Medina" formation.	
	163

Well on Perkins farm, northwestern part of Middleburg Township.

Big lime.	Feet.
Shale	59
Little lime	30
Shale	6
Clinton sand:	
White sand with gas	12
Shale and shell	13
White sand, no gas	10
Gray sand, no gas	10
Slate	50
"Medina" formation.	
	190

Well at Berea and Detroit avenues, near west limit of Cleveland.

Big lime.	Feet.
Slate	52
Stray sand	24
Slate	32
Little lime	4
Red rock	16
Clinton sand:	
White sand	3
Broken sand	12
White sand	5
Slate	15
Red rock	8
White slate	30
"Medina" formation.	
	201

Well near Lorain Road and Rocky River, West Park Township.

Big lime.	Feet.
Shale	10
Shell	10
Shale	15
Shell	4
Shale	37
Clinton sand	13
Shell, carrying oil in lower part	27
Shale	35
"Medina" formation.	
	151

The "Clinton" formation as a whole varies considerably in thickness, and it will be noted that the four sections just given show a range of 50 feet. The depth of the sand below the top of the formation ranges between 76 and 128 feet; the interval between its base and the "Medina" is 35 to 62 feet. The thickness of the sand itself is very irregular throughout the field, though the range from 13 to 45 feet shown by the foregoing sections is typical. The logs of all the wells yet drilled in Olmsted Township, on the west edge of the field, report the sand as entirely absent, and it is probably also lacking in much of the southern part of Dover and Rockport townships. In West Park Township the Clinton sand is generally between 5 and 30 feet thick, though where separated into two benches its total thickness may reach 50 or 60 feet. In the area east of the city line the sand is usually somewhat thicker, generally ranging between 30 and 60 feet, but in most of this area it is "broken" and nonproductive.

It is probable that the lenticular "stray" sands that may occur near the Clinton carry gas in some localities, but if so it is seldom reported. This may be due to the fact that when the true Clinton sand is barren and gas is found in another sand close to it the latter is likely to be erroneously reported as Clinton. A few wells have found shows of oil in "stray" sands, but most of the oil is regarded as coming from the lower red member of the Clinton sand.

The Clinton sand differs from most of the productive gas and oil sands of eastern fields in that it nowhere yields flows of water. The exact hydrologic character of the Clinton is somewhat uncertain because of the difficulty of completely casing off the large flows of water in the lower part of the Big lime before drilling into the sand, but drillers in the Cleveland field almost invariably report that the Clinton is dry, even where it is barren of oil or gas, and the sand is similarly described in most of the central Ohio fields. It is highly probable that the sand is not actually dry, and in many localities its pores may be entirely filled with water; the drillers' term "dry" implies merely that the sand does not yield water to the well. In other words, such water as the Clinton contains is generally not under high head or pressure and therefore does not migrate perceptibly. As the Clinton sand does not outcrop in northern Ohio large supplies of surface water can not enter it, and such a condition is therefore not surprising.

A peculiar feature of gas wells that penetrate the Clinton sand is their tendency to "salt up," a condition due to the accumulation of salt at the foot of the tubing, in some wells in sufficient quantity to seal them and shut off the flow of gas. In general the salt deposit is granular, but less commonly it is well crystallized. Various explanations have been advanced to account for this phenomenon; some believe that the salt occurs in the sand in the form of small grains and is blown through it by the gas, others that the sand carries some salt water, which is evaporated at the foot of the well, and others that salt water descends from the lower part of the Big lime. The first explanation is discredited by the fact that some of the salt is well crystallized and must therefore have been deposited from solution. The second is opposed to the general belief that the Clinton sand is practically dry, which is substantiated by the fact that few gas wells contain water even after the gas is practically exhausted. The third view seems more probable, for in many localities the salt water in the lower part of the Big lime is under considerable head and is very difficult to exclude completely from the wells. It is very probable that this water penetrates in small amounts to the foot of many wells, and that the deposition of salt is due to the evaporation of the water by the expanding gas. Even though the gas as it exists in the sand may be completely saturated with water vapor, the decrease in pressure and consequent increase in volume of the gas at the foot of the well would decrease the partial pressure exerted by the water vapor and enable the gas to take up more of it. The water in the lower part of the Big lime probably contains about 15 per cent of salts by volume, and the evaporation of a fairly small quantity of this water would therefore suffice to "salt up" a 2-inch tubing. Part of the water, however, with whatever salts it contains, is probably carried away mechanically by the gas, just as a salt mist is carried by the sea breeze.

GAS POOLS.

ROCKPORT POOL.

The Rockport pool, which occupies the narrow area between Detroit and Center Ridge roads, includes practically all the productive territory west of Rocky River. (See Pl. I.) The eastern part of this territory (see fig. 2, p. 40) is the richest, and most of the wells near the east end of Center Ridge Road had initial open flows of 3,000,000 to 8,000,000 cubic feet. (See table, p. 38.) Toward the west the wells become less productive, most of them flowing initially between 1,000,000 and 2,000,000 cubic feet, though one near the township line is credited with 3,108,000 cubic feet. The western limit of this pool has not yet been determined. All the wells produce from the Clinton sand, though one near the intersection of Center Ridge and Wagar roads reports 1,813,350 cubic feet from the Newburg sand.

Efforts to find extensions of this pool to the north and south have resulted in a number of dry holes, especially in the district near

Rocky River. (See fig. 2.) The only successful wells outside of the area described are two near Lake Road and the river. The larger of these wells reported a flow of 5,706,000 cubic feet, but they are surrounded by dry holes. The district between Center Ridge Road and the south township line has been tested by five wells, all of which are dry, and in two of which, according to report, the sand is absent. The logs of four wells drilled several years ago in the eastern part of Olmsted Township also report the sand as absent.

Although detailed information as to the structure in this region is not available, the productive area appears to be associated with a well-defined nose or plunging anticline. The axis of this small fold is about normal to the general strike, and the fold is believed to represent the western part of the larger structural nose with which the Cleveland field as a whole is associated. The fact that structure has played an important part in determining the position of this pool is indicated by the approximate coincidence of the productive area with the crest of the fold. Furthermore, the largest wells are those farthest down the dip, or nearest the general structural level of the large supplies of gas in the main field. This fact suggests that the sand becomes less productive up the rise and that the pool can not extend far west of the township line. On the other hand, the lithologic character of the sand undoubtedly has much to do with its productivity, and it is significant that the logs of all the wells outside of the productive area report the sand as absent or thin and broken.

BEREA POOL.

The valley of the east branch of Rocky River south of Berea has been rather extensively tested and has proved to be "spotted." The best pool yet discovered is directly south of Berea and extends half a mile into Strongsville Township. Two wells near the township line started at 3,000,000 cubic feet, and six had initial open flows of 1,000,000 to 2,000,000 cubic feet. There is one dry hole near the north end of the pool and three small producers in the southern part. About a mile south of the township line there are two dry holes, though a little farther south several good wells have been brought in.

Except in the area directly south of Berea prospecting in the southern two-thirds of Middleburg Township has been attended by rather discouraging results. Of 17 wells scattered over this area seven are dry and four produce only oil, in small amounts, from the red sand that forms the lower member of the Clinton. All the remainder are small wells except two, which started at 3,108,000 and 9,500,000 cubic feet, and the pool tapped by these two wells can not be large. The oil wells are in the eastern part of the township, and the oil-producing area appears to form an irregular belt that follows roughly the 1,000-foot contour and extends across the northwestern part of Parma Township, to the east. All the four wells drilled in Parma Township are oil wells.

The structure in the northeastern quarter of Middleburg Township appears to be favorable to the accumulation of gas, and the large proportion of barren territory in this area must be attributed to the "broken" character of the sand. The 9,500,000-foot well is near the center of the structural terrace that dominates this portion of the township, and most of the oil wells are at the base of the terrace. On the other hand, there are several dry holes and one oil well on the terrace, and the rich Brook Park pool lies to the northwest on a fairly regular monoclinal slope, which is nonproductive farther south. The southeastern part of the township is structurally unfavorable and so far as tested has proved barren. The Berea pool appears to be on a minor terrace, though the structure south of the township line was not determined. The accumulation of gas and oil in Middleburg Township seems to have been influenced in part by local structure but primarily by the character of the sand.

BROOK PARK POOL.

The Brook Park pool, which supplies about 85 successful wells, occupies an irregular area lying in the northwestern and northern parts of Middleburg Township and extending a short distance into West Park Township. It is the most recently developed pool of economic importance in the Cleveland field, but it appears to be now fairly well outlined by dry holes. (See Pl. I.) The richest part of the pool is on the township line between Berea and Harrington roads. Several wells in this locality had initial open flows of more than 5,000,000 cubic feet, and many others of more than 2,000,000, though there are also two dry holes. Toward the east and west along the township line the initial flows were somewhat smaller, averaging between 1,000,000 and 2,000,000 cubic feet. Several wells on the west side of Berea Road, about a mile south of the township line, had initial flows of more than 4,000,000 cubic feet, but the sand in this area is irregular, and close to the large wells there are several dry holes.

The southern and western borders of the pool appear to be sharply defined, and any extension of the productive area in these directions will probably be small and irregular. To the east the sand probably becomes oil bearing within a short distance. The northern edge of the pool is not yet determined, however, and the district west of Harrington Road and north of the Cleveland Short Line Railroad tracks should be tested.

Reference to Plate I shows that the Brook Park pool is at the northern edge of the structural terrace described above but lies chiefly on the general monoclinal slope. The largest wells seem to be in a small trough at the north edge of the terrace. The very irregular shape of the pool indicates that local structural conditions have had small part in determining its position.

WEST PARK POOL.

About two-thirds of West Park Township has been more or less closely drilled and may be considered as proved gas-producing territory. (See fig. 6.)

The district south of Lorain Avenue between Berea Road and Rocky River appears to be barren, with the exception of a small tract near the junction of Berea and Puritas Springs roads. One well in this tract started at 8,217,000 cubic feet, though it found the Clinton sand only 1 foot thick; several other wells started at about 2,000,000 cubic feet. It is possible that the productive area extends some distance to the west, but to the north and south it is bounded by dry holes. One well farther north found oil in the Newburg sand, and a well at Lorain Avenue and the river found a show of oil in the Clinton.

The district south of Lorain Avenue between Berea Road and the Lake Shore & Michigan Southern Railway tracks has been thoroughly tested but has not proved very productive. It contains a number of wells that produced initially between 1,000,000 and 2,000,000 cubic feet, but also many dry holes.

The southeast corner of the township is not regarded as favorable territory. A 7,277,800-foot well was finished in November, 1915, on the property of the American Agricultural Chemical Co., but six wells within 2,000 feet of this one proved dry. Two wells recently drilled in the extreme southeast corner of the township produced 20 and 30 barrels of oil. These wells are at about the same structural level as the oil wells in Middleburg and Parma townships, and it is probable that much of the area between the two groups will prove barren of gas but productive of oil.

One of the richest areas in the Cleveland field lies at the intersection of Puritas Springs and Harrington roads. One well in this area started at 12,913,000 cubic feet, four produced about 10,500,000 feet, eight others yielded about 5,000,000 feet, and eight averaged about 3,000,000 feet. This area is bounded on the north and west by several small producers and on the east by dry holes, but the district to the south should be tested. A short distance north of this pool, near the intersection of Moore Road and Lorain Avenue, there is a group of about 50 wells, all of which were successful. One of these wells started at 12,582,600 cubic feet and another at 10,590,000 feet, but most of the remainder produced initially between 1,000,000 and

3,000,000 feet. The log of one well reported a small amount of oil from a "stray" sand a short distance above the Clinton, and another well found 10 barrels of oil in the Newburg sand.

In the district lying between Lorain and Madison avenues west of Warren Road there are about 75 wells, of which only one is nonproductive. Most of the remainder had initial open flows of 1,000,000 to 4,000,000 cubic feet. The area between Warren and Bunts roads is somewhat more thickly drilled, containing about 60 wells and 1 dry hole. A well about a thousand feet east of the dry hole started at 7,366,000 cubic feet, but nearly all the remaining wells in this tract produced less than 3,000,000 cubic feet. The district between Bunts Road and the city line includes some of the most thickly drilled territory in the field, the area of 2 square miles shown in figure 6 containing 130 wells. This close drilling is due chiefly to the fact that much of the land has been subdivided into lots, for the territory is not particularly rich. Three wells started at 6,000,000 cubic feet and 18 at more than 4,000,000 feet, but most of them started at 2,000,000 feet or less, and 17 are reported as dry holes.

A number of wells were drilled along Madison Avenue east of the city line during the early period of the field's development, but nearly all these wells were small, and many of them started at less than 1,000,000 cubic feet. More recently a small pool has been discovered on Lorain Avenue about half a mile east of the city line. One well in this group started at 10,707,000 cubic feet and another at 7,786,500 cubic feet, but the remainder are small. Three of the wells stopped in the Newburg sand, finding flows of about 2,000,000 cubic feet.

The structure in West Park Township is dominantly monoclinal, and the many small undulations in the general slope appear to have had no influence on the accumulation of the gas. The average dip is 30 to 35 feet to the mile, which is somewhat lower than in the township to the south or in the area along the lake shore to the north. West Park Township occupies the central part of the broad, gentle nose already referred to (p. 15), and is therefore all favorable territory. Except in the southeast and southwest corners of the township the sand is clean and regular, and there are few barren areas. The proportion of large wells is not high, and the average initial flow was probably not more than 2,000,000 cubic feet, doubtless owing in part to the very large number of wells drilled.

LAKEWOOD POOL.

The Lakewood pool extends along the lake shore from Rocky River to a point a short distance east of the city line. It is separated from the West Park pool, to the south, by the well-defined barren area lying mostly between Madison and Detroit avenues. (See Pl. I.)

The western part of the Lakewood pool has not been so closely drilled as much of the older portion of the field, and most of the wells are between Lake Avenue and the lake shore. There are few large wells in this area, but several started at about 5,000,000 cubic feet and the average initial open flow is about 3,000,000 cubic feet. Because of the larger acreage per well the production has decreased less rapidly here than in many other parts of the field. A well near Clifton Boulevard and Webb Road found a show of oil in the Clinton sand, which is unusual in this part of the Cleveland field.

That portion of the Lakewood pool lying east of Giel Avenue is thickly drilled, there being 90 wells in an area of less than a square mile. (See fig. 8.) Wells 74 and 79 started at about 6,000,000 cubic feet, and five others at about 4,500,000 feet, but the average initial flow was less than 2,000,000 cubic feet (see table, p. 46), and there are three dry holes. Four of the wells stopped in the Newburg sand, finding flows of about 2,000,000 cubic feet. Well 83 encountered a flow of 6,056,850 cubic feet in the Newburg but penetrated to the Clinton and found only 2,193,000 cubic feet. Wells 75, 76, and 77 found shows of oil in the Clinton and also moderate supplies of gas.

The Lakewood pool apears to be on the edge of a sharp trough whose axis lies beneath Lake Erie. (See Pl. I.) The western part of the pool is apparently near the head of the trough, and the dip in that locality is to the east at about the normal rate. In the eastern part of the pool, however, the dip is north to northeast at a very much higher angle. A subsidiary trough enters the district at about the city line, and the three wells that found shows of oil are on its western flank. Elsewhere in the pool, however, local structural conditions appear to have had little influence on the accumulation of the gas, many of the good wells being located on the steep slope of the major trough and many others on the flat terrace to the south. The well-defined barren area south of the pool extends at right angles to the general strike and embraces minor undulations of both anticlinal and synclinal form.

CITY POOLS.

Two well-defined pools in the Newburg sand have been found in the city of Cleveland near Cuyahoga River, and a number of isolated wells have been drilled to the Newburg or Clinton in various parts of the city.

The older of the two pools in the Newburg sand, generally known as the Brooklyn pool, is on Cuyahoga River near the mouth of Big

Creek. The area north of the creek was first developed; the discovery well (No. 1, fig. 4) started at 12,500,000 cubic feet, and 11 of the other wells flowed initially between 4,000,000 and 9,000,000 feet. (See table, p. 40.) Twenty-five of the wells were drilled within an area of about 85 acres, and the decline was therefore rapid. South of the mouth of Big Creek the average initial production was somewhat smaller, though one of the wells started at 8,086,650 cubic feet and another at 5,257,500 feet. The sand is rather irregular throughout the pool, and six wells close to large producers were dry. The productive area is sharply delimited and forms a narrow strip along the river, the southern part of the strip being only a few hundred feet wide. The area embraced in this pool is so small that little can be ascertained regarding its structure, but the peculiar outline of the pool suggests that it may be associated with a small anticline.

The other pool in the Newburg sand is near the intersection of Walworth Avenue and West Twenty-fifth Street. The earlier wells in this area were of moderate capacity, but in July, 1915, one of the largest wells in the whole field, having an initial open flow of 13,384,000 cubic feet, was brought in here. Three other wells in this pool started at more than 4,000,000 cubic feet, but the remaining 10 averaged about 2,000,000 cubic feet. The pool is so small that the structure could not be made out.

About 50 wells have been drilled to the Newburg or Clinton in other parts of the city, but only one of them started at more than 3,000,000 cubic feet, and the greater number produced less than 1,000,000 cubic feet daily or were rated as dry. Five wells were drilled to the Newburg sand in the business district north of the Walworth Avenue pool; one started at 3,214,400 cubic feet, but two were dry, and the other two started at less than 500,000 cubic feet. Two wells a short distance northwest of the Walworth Avenue pool found a show of oil in the Clinton, and about a mile farther northwest there is another. About a dozen wells have been drilled close to the city line near the intersection of Ridge Road and Denison Avenue. All of them were small gas wells, whether stopping in the Newburg or penetrating to the Clinton, though one of those in the Clinton found 13 barrels of oil. In the district to the south, lying between Linndale and Brooklyn, 13 wells have been drilled to the Clinton sand. Of these, 7 are dry holes, and only 1 produced as much as 500,000 cubic feet of gas daily, but the remainder yield some oil. The logs of most of these wells report the lower red member of the Clinton sand, which is absent in most of West Park and Rockport townships. Between Brooklyn and the pool at the mouth of Big Creek 8 wells have been drilled; 6 were dry holes, but 1 produced 1,869,700 cubic feet from the Clinton and the other

2,750,000 cubic feet from the Newburg. About 20 wells have been drilled along the east side of Cuyahoga River close to or within the city limits. Nearly all these wells stopped in the Newburg sand, and had initial flows of 300,000 to 2,000,000 cubic feet, but 2 penetrated to the Clinton and found flows of about 1,700,000 cubic feet. A few other wells have been drilled in the eastern part of the city, but practically all of them found both Newburg and Clinton dry.

As shown on Plate I, the Clinton sand under the central and northeastern parts of the city appears to lie in a broad, flat terrace, the southern slope of which occupies the district between Brooklyn and Newburg. The portion of the terrace shown on the map may be regarded as barren except locally. The eastern limit of the commercially productive area is on the west or upper slope of the terrace, being associated in a general way with the 1,000-foot contour. A short distance below this contour is the irregular belt of wells that found small amounts of oil, and although some oil and gas have been found still farther down the dip the outlook for extensive development in that direction is not promising. The eastern slope of the terrace is east of the area shown on Plate I; this slope has not been tested and may prove productive, though the barren character of the south slope is not encouraging.

FACTORS IN THE ACCUMULATION OF THE GAS.

In attempting to find extensions of the Cleveland field or new pools in this region a knowledge of the factors that have influenced the accumulation of the gas is very desirable. It is a common belief, especially among oil and gas operators in northern Ohio, that geologic structure has had little to do with the position of pools in the Clinton sand and that variation in the porosity of the sand itself is the controlling factor. On the other hand, it is held by many that accumulations in the Clinton are controlled by terrace structure or by minor undulations in the monoclinal slope, and it has recently been shown that the pools near Wooster, 50 miles south of Cleveland, are closely associated with small anticlines.[1] If in the Cleveland region the texture of the sand is the controlling factor, a large number of dry holes must be expected in efforts to discover extensions of the field; but if structural conditions have played an important part, prospecting may be conducted more intelligently.

The Clinton sand is exceptional among important oil and gas reservoirs in that it does not crop out in the vicinity of its productive area. It rises from a great depth beneath the Appalachian coal basin, becomes somewhat thinner toward the west, and feathers out in central Ohio, where it approaches nearest the surface. The tendency of gas to migrate up the rise is generally considered the ultimate cause of its accumulation near Cleveland, as well as in the great belt to the south, for it is in this general zone that its upward migration is stopped by the thinning out of the sand. The sand does not disappear completely along a single regular line; there is a border zone in which it is present only in small irregular areas, some of which, like that at Oberlin, may prove productive. As the logs of a number of wells a short distance west of the Cleveland field report the sand as absent, the field appears to be on the eastern edge of the zone in which the sand is irregular.

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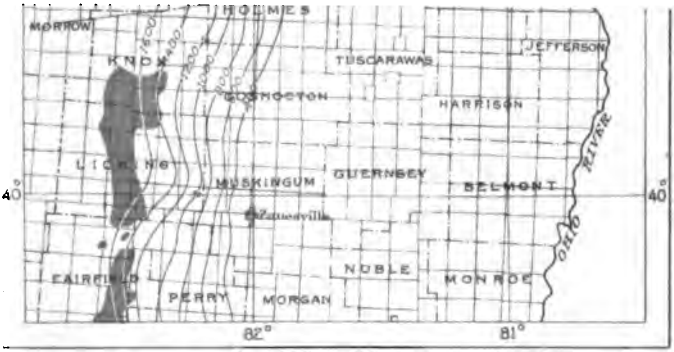
[1] Bonine, C. A., Anticlines in the Clinton sand near Wooster, Wayne County, Ohio: U. S. Geol. Survey Bull. 621, pp. 87–98, 1915.

Although the feathering out of the sand has determined the general position of the great Clinton gas fields, structural conditions have undoubtedly operated to localize the accumulations. In many of the southern fields and as far north as Wooster the gas is not accumulated directly at the edge of the sand, but has been trapped in structural irregularities a short distance below. In the writer's opinion, structural conditions have also controlled the accumulation of gas near Cleveland. The field as now developed is confined entirely to a very gentle structural nose or bulge; most of the oil occurs below the gas and approximately at one structural level, and below this level the sand appears to be practically barren of either oil or gas. Aside from this local structure, the marked change in the strike of the Clinton, forming an elbow or pocket near Cleveland, has probably also furthered the accumulation of gas in this locality.

A third condition affecting the accumulation of the gas is variation in the porosity of the sand, and this factor seems to have controlled very largely the detailed outline of the productive area and the position of the richer territory within it. In fact, the outline of the productive area is so irregular that at first sight it appears to have little relation to geologic structure. For example, the narrow and sharply defined strip of barren territory separating the West Park and Lakewood pools and extending at right angles to the strike can not be explained on structural grounds, nor can the irregular barren area on the minor structural terrace in the central part of Middleburg Township. These local variations must be attributed to the character of the sand, and it is only when the field is viewed broadly that the true significance of the structure becomes apparent.

As accumulations of gas in areas near by have probably formed under conditions similar to those in the Cleveland field, the foregoing conclusions furnish several suggestions for prospecting. It is evident, in the first place, that the Cleveland field is near the western limit of the general productive belt, and that the sand becomes irregular and discontinuous to the west. Productive areas may



INDEX MAP
SHOWING RELATIONS OF CLEVELAND FIELD AND GENERALIZED
STRUCTURE OF CLINTON SAND IN NORTHEASTERN OHIO

81°40′

Structural geology by
G. Sherburne Rogers

be discovered west of the Cleveland field, but such areas are likely to be small and prospecting for them will probably involve a number of dry holes. The zone in which the sand dies out trends somewhat west of south, however, and as prospecting continues south it may therefore be extended farther west. The eastern limit of the general productive belt can not now be determined. Although in the Cleveland field the territory below the 1,000-foot contour seems to be practically barren, farther south productive areas have been found at lower levels, correspondingly farther from the thin edge of the sand. The pools near Wooster, for example, extend at least as far down the dip as the 600-foot contour (2,400 feet below sea level). Furthermore, as the strike of the Clinton turns to the east near Cleveland, the sand may be found along the lake shore to the northeast at depths of 2,000 to 2,400 feet below sea level. (See index map, Pl. I.) This area has not been seriously tested, and although such results as have been attained are chiefly negative the district should not be condemned without further exploration. Southeast of the Cleveland field the depth of the Clinton sand increases rather rapidly and prospecting can not extend many miles in that direction.

The most favorable localities for prospecting within the area just outlined are those in which the dip of the Clinton changes in degree, and the larger accumulations of gas will probably be found in the structural irregularities so formed. The pools near Wooster are closely related to rather sharp anticlines; in the Cleveland district the structure is more gentle, but the field as a whole is confined to a broad nose. As the southern edge of this nose seems to be at Berea, the development on this particular structural feature may be regarded as already well outlined. Little is known of the detailed structure between Berea and Wooster, but it is highly probable that other noses, anticlines, or terraces exist. A sufficient number of wells have already been drilled in certain parts of this district to make possible a general comparison of the altitude of the sand at different points, and a study of this kind, supplemented if possible by an examination of the surface geology, would doubtless prove a valuable aid in prospecting. In the district east and northeast of Cleveland nothing is known of the detailed structure, and prospecting offers less chance of quick returns than in the area to the south.

Although structural conditions undoubtedly control the general position of the pools, it should be borne in mind that the character of the sand itself determines their detailed outline. One or two unsuccessful wells in an area of favorable structure do not necessarily condemn it; several of the earliest wells in the Cleveland field, put down close to what has proved highly productive territory, were dry. As a general rule the more pronounced the structure the more closely is the distribution of the gas related to it; where the structure is broad and gentle, as in the Cleveland field, the character of the sand becomes a more important factor.

QUALITY OF THE GAS.

The chemical constitution and heating value of Clinton gas in the Cleveland field are shown by the first two analyses in the following table. Analysis 3, representing Clinton gas from the Thurston field in Fairfield County, is added for comparison. Analysis 4 represents a sample of gas that was collected in Cleveland before 1894 and therefore is presumably shale gas.

Analyses of gas from Cleveland and Thurston fields.

	1	2	3	4
Carbon dioxide (CO_2)	0.2	0.0	0.25	0.20
Carbon monoxide (CO)	.8	.6	.15	....
Oxygen (O_2)	.3	.1	.15	.00
Hydrogen (H)	3.7	1.6	.55	.00
Methane (CH_4)	91.2	95.5	....	....
Olefines	....	....	.30	....
Illuminants	1.1	.2	....	....
Total paraffins	....	....	90.48	93.50
Nitrogen (N_2)	2.7	2.0	8.12	6.30
	100.0	100.0	100.00	100.00
Heating value, in British thermal units	1,089	1,105	....	....

1 and 2. Clinton gas from numerous wells in Lakewood and West Park pools, Cleveland field. Analyses by C. P. Linder for East Ohio Gas Co., 1915.
3. Clinton gas from Thurston field, Fairfield County. Analyst, C. C. Howard. Cited by Bownocker, J. A., Am. Geologist, vol. 31, p. 230, 1903.
4. Gas from well in Cleveland (probably shale gas). Analyst, F. C. Phillips, Am. Chem. Jour., vol. 16, p. 416, 1894.

Analyses 1 and 2 indicate that the Clinton gas of the Cleveland field is a high-grade fuel composed almost entirely of methane and higher hydrocarbons. The oxygen and much of the nitrogen reported are probably due to admixture of air in the samples analyzed, so that the minor constituents of the gas are chiefly hydrogen and carbon monoxide.[1] Analyses 3 and 4, though showing higher percentages of nitrogen, represent gas essentially similar to that of the Lakewood and West Park pools.

Although no analysis of gas from the Newburg sand is available, a number of determinations of its heating value, made for the East Ohio Gas Co., indicate that it is very similar in composition to gas from the Clinton sand. According to these tests the heating value of the Newburg gas ranges between 1,035 and 1,120 British thermal units and that of the Clinton between 1,050 and 1,110 British thermal units; the average for each is about 1,080 British thermal units.

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[1] Burrell and Oberfell (Bur. Mines Tech. Paper 109, p. 11, 1915) state that they have found no hydrogen or carbon monoxide in any of the numerous samples of natural gas tested by them. They believe that these substances are not present in natural gas and ascribe the fact that they are frequently reported to unavoidable errors involved in the ordinary methods of gas analysis.

TECHNOLOGIC FEATURES OF THE FIELD.

The Clinton sand wells in the Cleveland field are from 2,500 to 2,900 feet deep; the deeper wells are in the southern and eastern parts of the field. Most of the Newburg sand wells are about 2,400 feet deep, and the shale wells from 600 to 1,200 feet deep. Most of the shale wells were drilled with a portable rig, but all the Newburg and Clinton wells were drilled with a derrick and cable tools. The average time of drilling for the deep wells is 40 days, and the average cost between $5,000 and $6,000. In the district between Rocky River and the city line the dip of the Clinton is so regular that many of the wells were drilled under contract at a flat rate for the finished well rather than at so much per foot.

Three strings of casings are generally used in drilling, with one or more joints of 10-inch casing at the top as a conductor. The 8-inch casing used to shut off surface water is generally 70 to 170 feet long. The salt water in the upper part of the Big lime is cased off with $6\frac{5}{8}$-inch casing at a depth of 1,450 to 1,700 feet. If the well extends to the Clinton the salt water encountered a short distance below the Newburg sand is shut off between 2,450 and 2,700 feet with $5\frac{3}{16}$-inch casing. This casing, as well as the tubing inserted later, is packed in order to exclude the salt water from above. Many of the wells, especially the smaller ones, in which the sand is dense and hard, are shot with nitroglycerin, the average charge being 30 to 40 quarts. Although in some wells this does not increase the flow of gas, it generally proves advantageous, and in one well near Harrington and Puritas Springs roads served to increase the flow from 591,000 to 3,108,000 cubic feet. When the well has been shot the strings of larger casing are pulled, the tubing is set, and the derrick is removed.

The life of a gas well depends to a considerable degree on the manner in which it is handled. The water in the Big lime may be under a head of 2,000 feet, and it is very difficult to exclude this water completely by the use of packers alone. A factor of great importance is the pressure of the gas itself, which tends to hold back this water, and if the well is drawn on to its full capacity and the pressure rapidly reduced the water may invade the sand and ruin the well early in its career. In many wells a small amount of water probably does pass the packers and on evaporation causes the well to "salt up," as already described. The salt is generally removed by forcing a little fresh water or steam into the well and closing it for a day or two, at the end of which the water is expelled by opening the valve wide and allowing the well to flow. Most of the wells are free from water troubles, in the ordinary sense of the term, but "salting up" is very common. As the Clinton sand when first penetrated by the drill is almost invariably reported to be free from water, the removal of the gas is not accompanied by the invasion of water from lower levels, as in many other fields.

PRODUCTION OF THE FIELD.

The quantity of gas produced in Cuyahoga County during the years 1911 to 1915 is given in the following table, which has been compiled by Miss Belle Hill under the supervision of J. D. Northrop. The gas produced from shallow wells stopping in the Ohio shale is separated from that furnished by deep wells drilled to the Newburg or Clinton sands. The total production of Ohio during the same period is added for comparison. During the years indicated practically all the gas produced from the Newburg and Clinton sands in Cuyahoga County came from the area discussed in this report and shown in Plate I, though in 1916 some gas was produced in the district to the south.

Natural gas produced in Cuyahoga County and in Ohio, 1911–1915.

Year.	Ohio (cubic feet).	Cuyahoga County.		
		From deep wells.		From shallow (shale) wells (cubic feet).
		Cubic feet.	Per cent of State's production.	
1911	49,449,749,000	0	0	116,090,000
1912	56,210,052,000	548,934,000	0.9	96,977,000
1913	50,612,211,000	1,536,087,000	3.0	[a] 96,977,000
1914	68,270,174,000	16,256,705,000	23.8	[a] 101,000,000
1915	79,510,032,000	31,346,831,000	39.4	[a] 101,000,000

[a] Estimated.

The following table records by years the number of deep (Newburg and Clinton) and shallow (shale) wells drilled in Cuyahoga County from 1911 to 1915, and shows the status of development on June 1, 1916. Of the 855 deep gas wells completed by that date 743 draw their supplies from the Clinton sand, only 112 stopping in the Newburg. Of the dry holes drilled 144 penetrate both Newburg and Clinton, the remaining 10 extending only to the Newburg.

Wells having an initial open flow of less than 250,000 cubic feet are commonly considered dry in the Cleveland field. The wells classified in the table as dry include those reported as dry by the owner and also those whose initial open flow was measured and found to be less than 250,000 cubic feet.

Wells drilled for natural gas in Cuyahoga County, 1911-1916.

Year.	Deep wells.				Shallow (shale) wells.			
	Drilled.		Abandoned.	Productive Dec. 31.	Drilled.		Abandoned.	Productive Dec. 31.
	Gas.	Dry.			Gas.	Dry.		
1911	1	0	0	1	20	3	21	609
1912	9	6	0	10	16	4	47	578
1913	17	7	0	27				[a] 578
1914	377	55	43	361				[a] 567
1915	412	57	147	626				[a] 567
To June 1, 1916	855	154	[a] 326					

[a] Estimated.

These tables show plainly the exceptionally rapid rise of the Cleveland field, which in 1912 contributed only 1 per cent of the State's production but in 1915 yielded about 39 per cent. The output in 1915 probably represents the maximum yearly production from the Cleveland field proper, for practically all the area shown in Plate I has either been thoroughly drilled or proved unproductive. The production of the county as a whole for 1916 may, however, be increased by the development of new territory to the south.

The approximate extent of the territory now developed in the Cleveland field is 27 square miles, divided as follows:

	Square miles.
Clinton sand:	
West Park and Rockport pools	12.3
Brook Park pool	4.7
Lakewood pool	3.0
Berea pool	.6
Eastern part of Middleburg Township (mostly oil)	2.2
Linndale area (mostly oil)	.7
Areas in city	.5
	24.0
Newburg sand:	
Brooklyn pool and area on Cuyahoga River	2.3
Walworth Avenue pool	.7
	3.0

The life of the field as now developed is difficult to estimate but probably will not be more than three or four years. During 1914 a back pressure of 130 to 150 pounds was maintained on the wells in the West Park and Lakewood districts, but in the Brooklyn pool the pressure was somewhat lower. In 1915 it was found necessary to reduce the pressure throughout the older portion of the field, and in the Brooklyn pool it was finally lowered to 20 pounds. It has now been lowered to 40 or 50 pounds in the Lakewood pool and part of the West Park pool, and the use of compressors will soon be necessary in those districts. Pumps are now being installed on some of the wells. In the district west of Rocky River, in the southern part of West Park Township, and in Middleburg Township the rock pressure is still high, however, and a considerable back pressure is maintained.

A large proportion of the gas produced in the Cleveland field is bought by the East Ohio Gas Co. at 6 cents a thousand cubic feet and supplied for domestic purposes and manufacturing to the city of Cleveland. The average daily production from the field, which was about 85,000,000 cubic feet in 1915, is not sufficient to supply the city, however, and a considerable quantity of gas is transported by pipe line from the West Virginia fields. Some of the gas produced in Middleburg Township is sold to the Berea Pipe Line Co., which supplies Berea and several other towns in Cuyahoga and Lorain counties, and a little is taken by other distributing companies. A number of manufacturing firms in Cleveland produce gas for their own use, but in 1915 the quantity of gas not sold to distributing companies represented only 8.6 per cent of the field's production.

The gas produced by some of the wells contains a little gasoline, which may be condensed as pipe-line "drips" or extracted by compression. Gasoline has been condensed on a small scale, but no commercial production is reported.

A little oil has been produced in the field since 1912, but no estimate of the quantity prior to 1915 is available. In 1915 the Buckeye Pipe Line Co. completed the Cleveland division of its lines and in the last quarter of the year 1,830 barrels were sold, and during the first half of 1916 the monthly production averaged more than 1,000 barrels. This increase was due chiefly to the completion of a number of oil wells in the district between Berea, Linndale, and Brooklyn. It is probable that with the advent of facilities for handling the oil the production will still further increase, for there is yet promising territory to be drilled.

The quantity of gas produced by shallow wells from the Ohio shale does not vary greatly from year to year. It represents only a small fraction of the State's production, but, as is indicated by the large number of shallow wells, this gas is widely distributed through the county and constitutes the domestic supply in many homes.

DECLINE OF WELLS.

GENERAL CONDITIONS.

The rapid decline of individual wells in the more closely drilled districts of the Cleveland field has already been referred to. It has long been realized by those familiar with the gas industry that a closely drilled field is short lived, but the widespread ignorance of this principle among the people at large is only too clearly shown by the uneconomic manner in which much of the Cleveland field has been developed. The number of gas wells per square mile that may profitably be drilled depends largely on the thickness and porosity of the sand, on the original rock pressure, and on the prevailing price of gas, and is therefore different in different fields; but in every field there is a limit, and this limit is smaller than is commonly supposed. The first wells drilled in a small pool are generally very profitable, but the profit decreases rapidly as the number of wells increases, and the last wells drilled may not produce enough gas to pay for themselves.

Although the Cleveland field is a conspicuous example of wasteful development, it is probable that many other eastern gas fields contain a larger number of wells than is necessary or profitable. The failure to realize the economic loss entailed by overdrilling may be due to the fact that exact figures showing the decline of gas wells have seldom been published, though generalized statements are common. The figures given below are regrettably incomplete, but they serve at least to show the general trend of decline and to give a rough quantitative expression to certain principles whose significance may not be fully appreciated by many operators. They are given, not with the idea that they can be directly applied in other fields, but in the hope that they will arouse the interest of operators and stimulate the general tendency toward the recording of more complete and more accurate data. It is believed that if fairly complete records of the decline of wells in various fields were available for careful analysis, it might be possible to draw standard curves that would prove valuable guides in the development of new fields.

The principal geologic factors controlling the production and life of a well, as already shown, are the position of the well with reference to the structure, the porosity of the sand, the thickness of the sand, the pressure, and the presence or absence of water. Other important factors are the amount of water that may penetrate to the sand from above, which depends chiefly on the manner in which the casing is set; the question whether or not the sand has been shot; the care taken of the well after it has begun to produce; and the number of days per month it produces. Because of variation in these and other factors the history of each well is peculiar, and no one well can safely be selected as entirely representative of all the wells in even a small pool. In the Cleveland field, however, there are many small groups of wells in which the geologic conditions are essentially uniform; and as most of the wells were drilled and finished by standardized methods and were then taken over by one distributing company and operated under practically the same conditions, the variation in the technologic factors is probably as small as can be expected.

PRESSURE AND FLOW.

In measuring the capacity of gas wells two factors are commonly determined—the rock pressure and the open flow. The term "rock pressure" is used to designate the pressure under which the gas occurs in the sand. It is determined in pounds per square inch by means of a gage attached to the well and read when the pressure has attained a maximum after the well has been closed for 24 hours or longer. The open flow of the well is the volume of gas delivered against atmospheric pressure in a given length of time, usually 24 hours. It is determined by allowing the well to flow freely for several hours and measuring the "open-flow" pressure or velocity of the gas, from which the volume may be computed.

The volume of gas delivered by a well under a given open-flow pressure depends partly on the size of the bottom of the well and the diameter of the casing and partly on the porosity and the thickness of the sand. It is evident that the larger the cavity at the foot of the well and the larger the casing the greater will be the flow; and, according to the same principle, if the sand at the foot of the well is open and has a high porosity a greater volume of gas can pass through it in a given time than if it were tight or shaly. As the size of the casing is the same in practically all the wells in this field, much of the difference in the flow of neighboring wells may be ascribed to difference in the porosity of the sand from which they draw their supplies. The rock pressure, on the other hand, is not affected by minor variations in the porosity of the sand, and the whole body of gas in a pool of moderate size is theoretically under about the same rock pressure. If two neighboring wells, one producing a large volume of gas and the other a small volume, are closed, the rock pressure registered by both will be about the same, but the large well will register this pressure almost immediately, whereas the small one may remain closed for some time before its pressure reaches the same figure. A high rock pressure, therefore, does not necessarily entail a high flow, and several wells in the Cleveland field that registered a rock pressure of over 600 pounds had an open flow of less than 300,000 cubic feet. On the other hand, a high flow is usually accompanied by a high rock pressure, and the flow and pressure decline at about the same rate. The flow of a well is greatly influenced by local conditions, such as the porosity of the sand, but the rock pressure is a more uniform feature, and its decline in a small pool is therefore a convenient and accurate index of the stage of exhaustion of the reservoir.

DECLINE OF ROCK PRESSURE

GENERAL FACTORS.

The initial rock pressure of the earlier wells in the Cleveland field ranged between 800 and 1,100 pounds per square inch. Since these wells were drilled their rock pressures have declined steadily and the initial pressure of wells drilled later has been correspondingly lower. As the Cleveland field is made up of a number of small pools separated by areas in which the sand is dry and apparently impervious to gas, the rate of decline of the rock pressure, which depends on the rate at which gas is removed from the sand, is different in different parts of the field. There are still areas in which new wells would show a pressure of more than 800 pounds, but in some of the older and more closely drilled tracts the initial pressures had fallen as low as 175 pounds within eight months after the first well was drilled.

The initial rock pressures of over two-thirds of the wells in the field have been determined by the East Ohio Gas Co. It has been found that if a small unified area is considered the initial pressure of each successive well drilled is, in general, lower than that of the last, showing that the pressure of the whole body of gas within the area is practically equalized and declining at a fairly uniform rate. If all the wells in a larger area are considered, however, the decline is much less regular, for the gas is removed at different rates in different districts, and variations in the porosity of the sand retard or prevent equalization of the pressure. The writer has therefore selected several small but representative groups of wells and has plotted their initial pressures in order to show the general decline of the whole field. Unfortunately records of the decline of the pressure during the life of individual wells are available for only a few wells, but it is believed that the curve showing the decline of initial pressures of all wells within a small group is essentially the same as one that would show the decline during the life of a single well. The initial pressure of a new well is generally somewhat higher than the pressures of neighboring wells on the same date, but in this field the difference is seldom large.

ROCKPORT GROUP.

A group of 12 wells at the east end of the Rockport pool, shown in figure 2, has been selected to show the rate of pressure decline in the less thickly drilled part of the field. The 12 wells are within an area of about 80 acres, but their drainage area is somewhat greater. In the western part of the Rockport pool and in the Brook Park pool the wells are spaced farther apart, but data regarding rock pressures in these areas are not available.

The accompanying table shows the date on which each well in the group was brought in and the pressure and flow of the well on that date. The original pressure in the area was evidently 1,050 pounds, but in six months it had declined to 775 pounds, the initial pressure of each successive well, with two exceptions, being lower than that of the preceding well. Measurements of the pressure of four of the wells on August 15, 1915, show that the decline continued at about the same rate, even though only two wells (Nos. 32 and 33) were brought in after the pressure had dropped to 775 pounds. These data are shown graphically in figure 3.

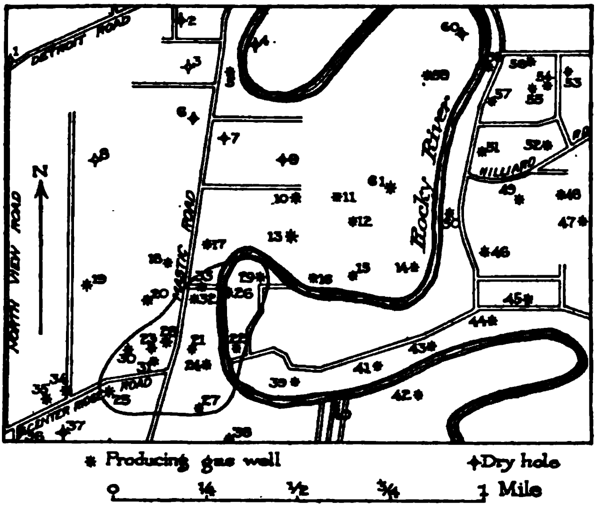

FIGURE 2.—Map of east end of Rockport pool, Cleveland, Ohio. The initial rock pressures of wells in the area inclosed by the line (referred to as the Rockport group) are shown in figure 3.

Rock pressure and open flow of wells in Rockport group, between Rocky River and Center Ridge Road.

No. of well on map (fig. 2).	Date brought in.	Initial rock pressure.	Initial open flow.	Rock pressure Aug. 15, 1915.
	1914.	*Pounds.*	*Cubic feet.*	*Pounds.*
21.......	Nov. 25	1,050	7,366,000	505
22.......	Dec. 8	1,000+	3,108,000	....
	1915.			
23.......	Jan. 26	950	6,000,000	545
24.......	Jan. 30	895	7,033,000	....
25.......	Feb. 12	850	617,300	....
26.......	Feb. 16	925	6,500,200	....
27.......	Mar. 20	840	1,101,000	510
28.......	Apr. 7	800	3,574,600	540
29.......	Apr. 8	860	3,854,500	....
30.......	Apr. 20	860	3,861,000	....
31.......	May 18	775	4,917,000	....
32.......	June 5	(?)	4,389,000	....
33.......	Sept. 4	(?)	2,193,000	....

It will be noted that the line of initial pressures is remarkably regular, except in two places; the pressures of wells 24, 25, and 28 seem to be abnormally low and those of wells 29 and 30 unusually high. The low pressures of wells 24 and 28 are explained by the fact

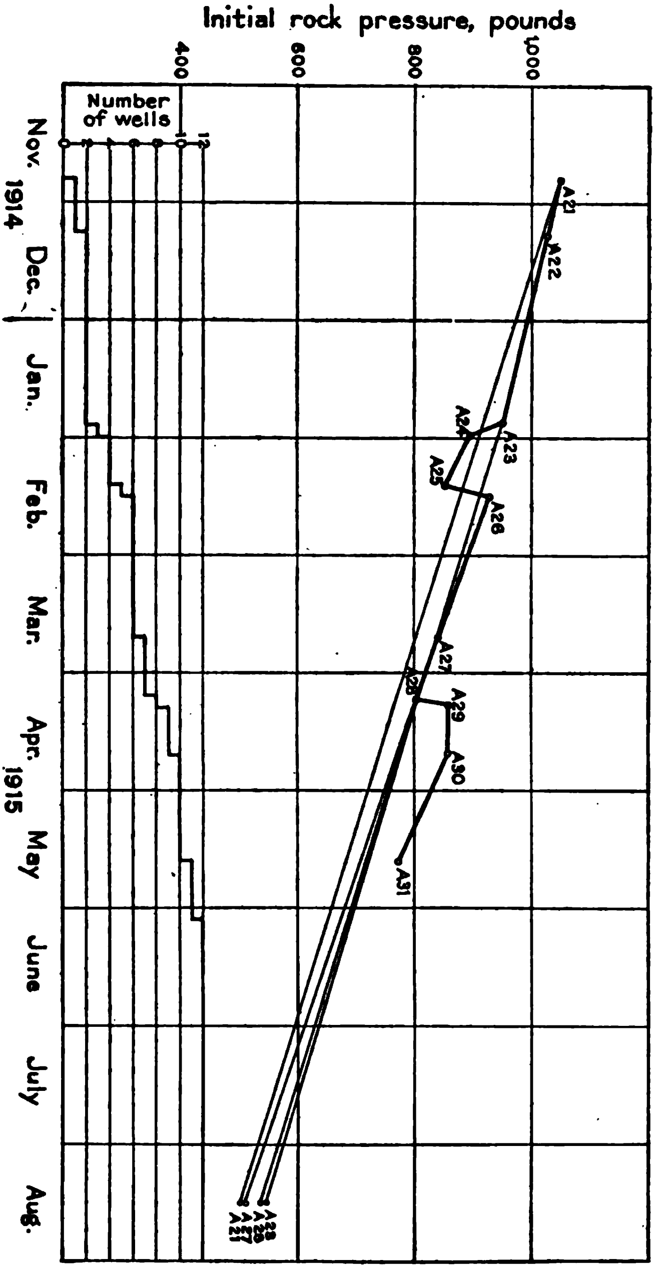

FIGURE 8.—Diagram showing decline of rock pressure in wells in Rockport group, Cleveland, Ohio. A21, A22, etc., refer to wells 21, 22, etc., in figure 2. Heavy line shows decline in initial rock pressure; light lines show decline in pressure of individual wells.

that they were drilled close to the older wells 21 and 23. The high pressures of wells 29 and 30 are probably due to the fact that they were drilled near the edge of the group, where the pressure had not yet been reduced by other wells. The straight lines connecting the initial pressures of the wells with the pressures five months or more later have about the same slope as the curve of initial pressures, indicating that the decline of individual wells is essentially coincident with the decline of the whole group.

BROOKLYN GROUP.

A more rapid decline of rock pressure is shown by a group of 25 wells in an area of about 86 acres in the northern part of the Brooklyn pool near the mouth of Big Creek. (See fig. 4.) This is one of the most thickly drilled tracts in the Cleveland field, and represents the extreme of uneconomic development, for there is no reason to doubt that one well in a somewhat longer time would have removed the gas as completely as the 25 wells drilled.

The accompanying table shows the dates on which the wells were brought in, their initial pressure and flow, and for some the dates on which they were abandoned. As the first three wells were not gaged, the original pressure of the pool is not known, but it was probably about 1,000 pounds. The first nine wells reduced the pressure to 645 pounds in four months, however, and the 12 wells drilled in the next three months reduced it to less than 300 pounds. Many of the wells were exhausted within six months and the flow of the remainder was reduced to a fraction of its original volume.

Statistics of wells in Brooklyn group.

No. of well on map (fig. 4).	Date brought in.	Initial rock pressure.	Initial open flow.	Date abandoned.	Life of well.
	1914.	*Pounds.*	*Cubic feet.*		*Months.*
1	Feb. —	(?)	[a] 12,500,000	Oct. 10, 1914	8
2	Mar. 15	(?)	1,979,600	do	7
3	Mar. 28	(?)	[b] 4,552,900	do	6
4	Apr. 28		Dry.	Apr. 28, 1914	0
5	Apr. 12	750	4,552,900		
6	Apr. 16	(?)	350,900	Jan. 4, 1915	9
7	Apr. 17	(?)	6,800,000	May 26, 1915	13
8	Apr. 20	(c)	5,571,900	Mar 14, 1916	23
9	Apr. 24	(?)	3,214,400	Jan. 14, 1915	9
10	June 6	645	1,117,400		
11	do	490	3,829,000	Mar. 14, 1916	21
12	June 11	465	711,800		
13	June 13	390	969,800	Nov. 19, 1914	5
14	June 19	430	3,706,200		
15	do	420	3,214,400	Nov. 1, 1914	4
16	June 30	515	[d] 4,885,000		
17	July 7	450	216,000		
18	Aug. 6	280	2,514,700		
19	Aug. 18	450	1,008,000		
20	Aug. 29	410	877,100		
21	Sept. 4	350	330,700		
22		(?)	7,194,300		
23		(?)	554,400	Oct. 1, 1914	
24		(?)	319,700		
25		(?)	304,200		

[a] Decrease in flow at end of 4 months, 77 per cent.
[b] Decrease in flow at end of 2 months, 66 per cent.
[c] On June 22, 395 pounds.
[d] Decrease in flow at end of 12 months, 81 per cent.

The decline of initial pressures in the Brooklyn pool is shown in figure 5. As a number of wells are involved, there are some irregularities, and the curve shown is therefore a sketched average. Most of these irregularities are explained by reference to the map. Well 10, for example, had an abnormally high pressure because of its distance from the wells already drilled, whereas the low pressure of well 13 is due to its close proximity to four older wells. It will be noted that the period of greatest decline was in April, May, and

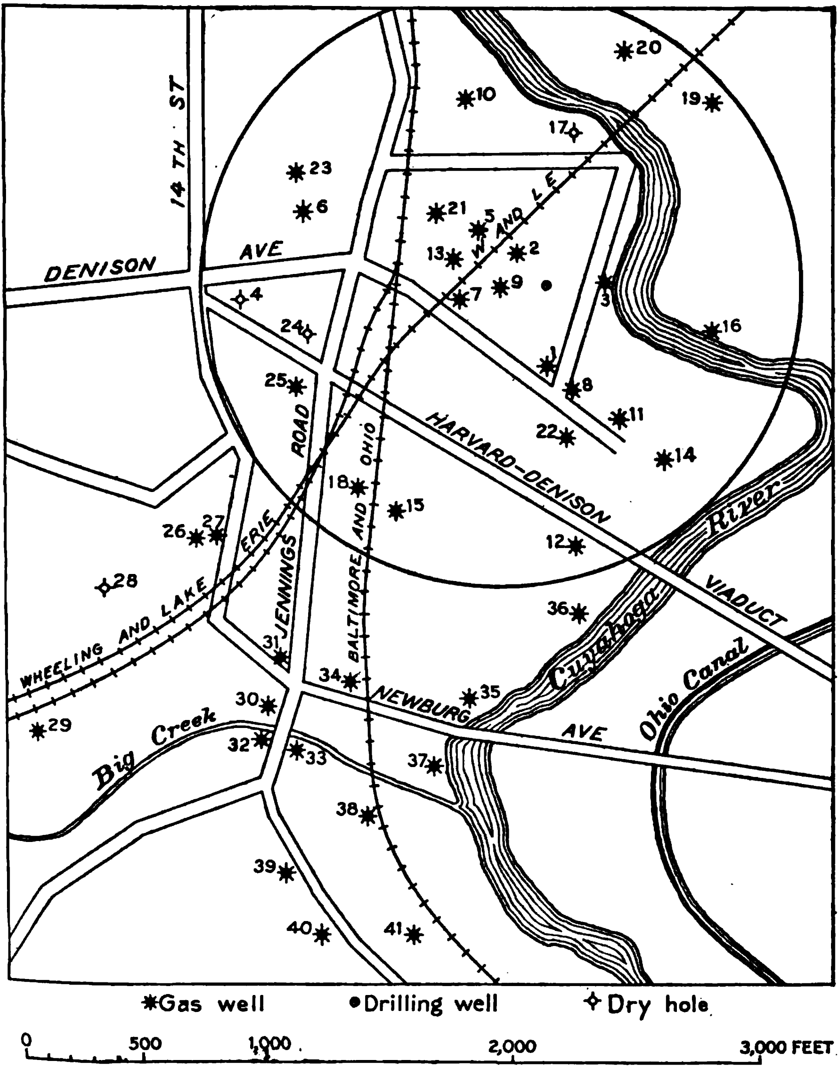

FIGURE 4.—Map of northern part of Brooklyn pool, Cleveland, Ohio. Statistics of wells in area within circle (referred to as the Brooklyn group) are given in the table on page 40 and in figure 5.

June, when most of the wells were drilled, and that cessation of drilling for a few weeks in July and August tended to flatten the curve. The reduction in pressure for the five-month period averaged 95 pounds per month, as against 45 pounds per month in the less closely drilled Rockport pool.

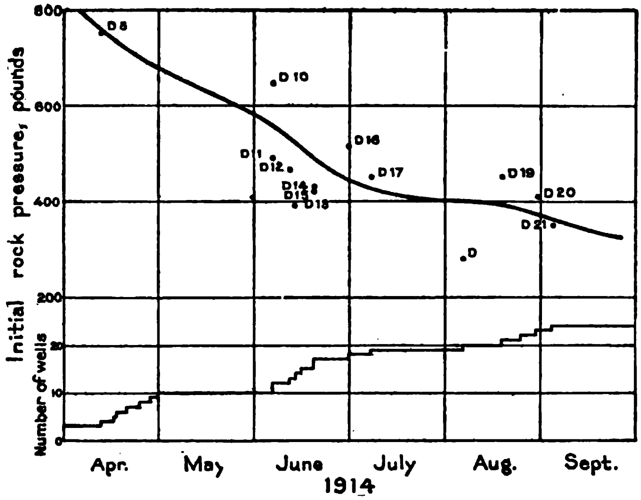

FIGURE 5.—Sketched curve showing average decline of initial rock pressures of wells in Brooklyn group, Cleveland, Ohio. D5, D10, etc., refer to wells 5, 10, etc., in figure 4.

WEST PARK GROUP.

A group of 35 wells drilled near Vinton Row, in West Park Township, furnishes an interesting study in the decline of rock pressure. (See fig. 6.) Although the area involved is only about 70 acres, it is separated into two districts by a patch of barren sand, and the initial pressures of successive wells in this area fall naturally into two distinct curves. The statistics of the wells are given in the accompanying table. Wells 132 to 145 are in the northern productive district and wells 94 to 108 in the southern; wells 126 to 131 are in the practically barren area between.

Statistics of wells in West Park group, Vinton Row and Lorain Avenue.

No. of well on map (fig. 6).	Date brought in.	Initial rock pressure.	Initial open flow.	Date abandoned.	Life of well.	Depreciation.	
						Period.	Per cent.
Northern district.	1914.	*Pounds.*	*Cubic feet.*		*Months.*	*Months.*	
132	Mar. 4	([a])	6,391,000	Apr. 16,1915	13		
133	Mar. 15	625	786,700	Sept. 25,1915	18	16	88
134	do	560	3,823,400	Oct. 22,1915	19	16	98
135	May 5	[b] 305	1,759,800	Nov. 29,1915	19	14	87
136	May 8	360	681,100				
137	do	350	1,554,000	Nov. 29,1914	6		
138	May 25	300	824,000	June 22,1915	13		
139	June 13	300	789,500				
140	June 14	260	554,400				
141	June 20	220	1,047,600	Dec. 23,1915	18	13	85
142	July 23		2,131,200	Oct. 15,1915	15	11	97
143	Aug. 8	(?)	380,200	Feb. 12,1915	6		
144	Sept. 21		Dry.	Sept. 21,1914	0		
145	Oct. 29	165	368,600	Mar. 4,1915	5		
Barren area.							
131	June 24		Dry.				
130	June 12		Dry.				
129	May 16		Dry.				
128	July 3		Dry.				
127	May 28	560	304,300				
126	Aug. 22		Dry.				
Southern district.							
94	June 6	435	879,800	Mar. 27,1915	10		
95	July 9	940	5,256,200			12	86
96	July 14	(?)	300,000	Jan. 27,1915	6		
97	Aug. 21	(?)	2,921,000			10	71
98	Sept. 9	(?)	6,670,800			10	89
99	Oct. 20	700	4,098,600			9	79
100	Nov. 13	600	6,498,000			8	91
101	Dec. 4	470	2,694,000			7	66
102	Dec. 11	440	2,494,800			6	80
103	Dec. 18	550	4,389,000			6	86
104	Dec. 22	415	1,902,000	Mar. 14,1916	15	6	95
	1915.						
105	Jan. 5	(?)	1,902,000	Jan. 24,1916	13	6	80
106	Jan. 7	470	3,781,800			5	53
107	Jan. 19	350	2,500,000			4	18
108	Mar. 26	325	1,554,000	Mar. 14,1916	12	3	25

[a] Not measured till May 26, 1914, when it was 290 pounds.
[b] On July 20, 1914, had decreased to 205 pounds.

Figure 7 shows the initial rock pressures of the wells in the two productive districts. The pressure in the northern district at the time drilling started was probably less than 800 pounds; the first well was not gaged, but the second and third wells, which came in 11 days later, had pressures of 625 and 560 pounds. The later wells showed steady decrease in pressure, that of well 145, brought in eight months after the first well, being only 165 pounds. Four months after the first well was finished in the northern district well 94 was drilled in the southern area and showed an initial pressure of only 435 pounds. The low pressure of this first well is difficult to explain, for the second well started at 940 pounds, and the next gaged (the sixth) at 700 pounds. Drilling in this area continued for about 10 months with steadily declining pressures, the last well starting at 325 pounds.

The pressures of all the wells except No. 94 fall close to the curves sketched in figure 7. It will be noted that these curves differ somewhat in shape, but the difference is largely explained by inspection of the well drilling curves. In both districts the period of greatest decline coincided with the period in which the largest number of wells were brought in. The difference in shape is also due in part to the fact that only the lower portion of the curve for the southern district is shown, for the pressure in this district had already been somewhat reduced by older wells a short distance to the northwest.

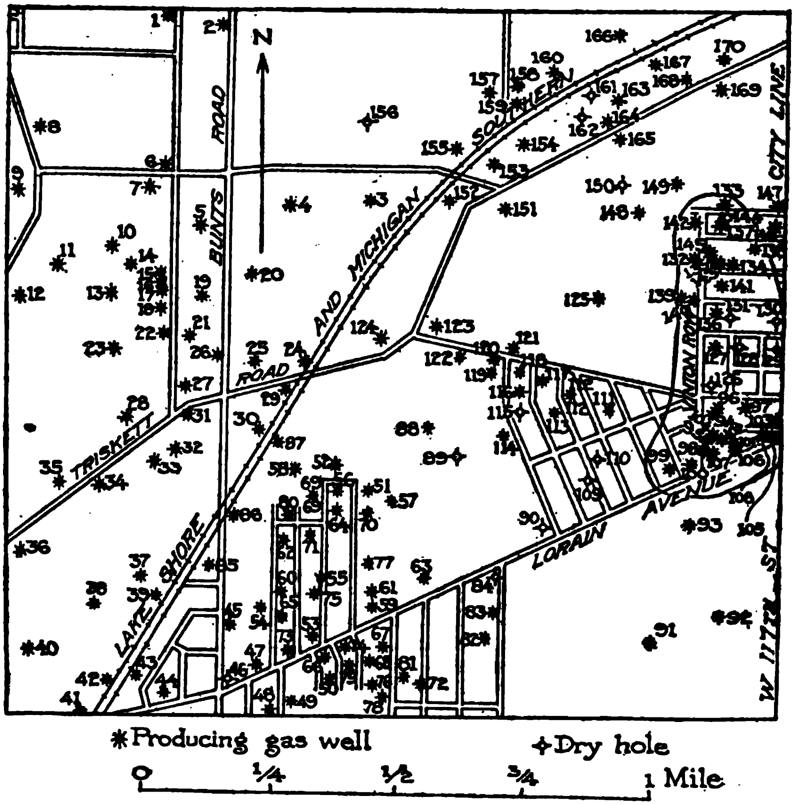

FIGURE 6.—Map of northeastern part of West Park pool, Cleveland, Ohio. Statistics of wells in area inclosed by line (referred to as the West Park group) are given in the table on page 43 and in figure 7 and Plate II.

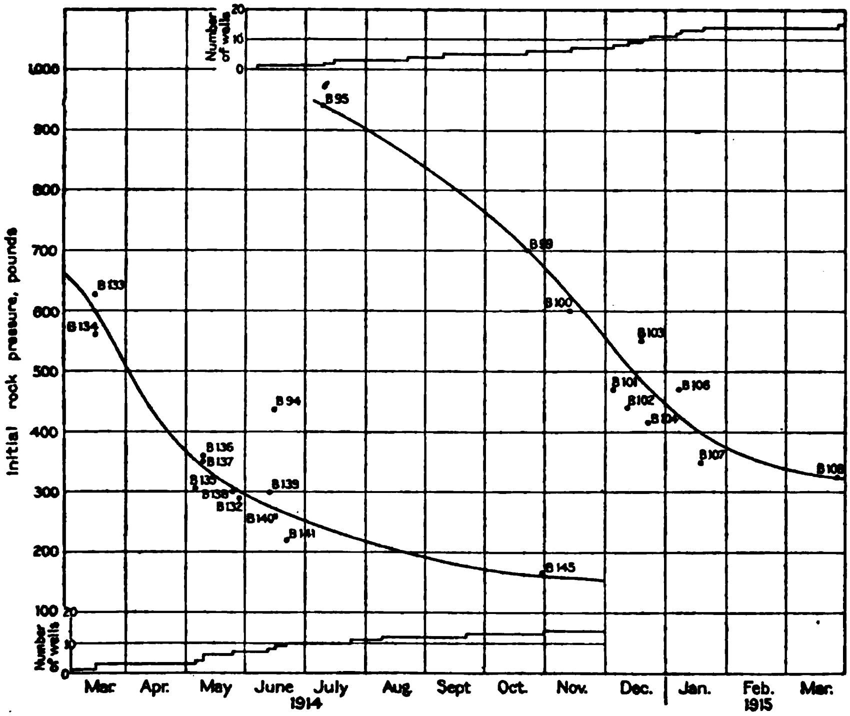

FIGURE 7.—Sketched curves showing average decline in initial rock pressure in two neighboring groups of wells in West Park pool, Cleveland, Ohio. B94, B95, etc., refer to wells 94, 95, etc., in figure 6.

LAKEWOOD GROUP.

A group of 36 wells in the eastern part of the Lakewood pool furnishes another example of the decline of initial pressures. (See fig. 8.) These wells are drilled in an area of about 100 acres.

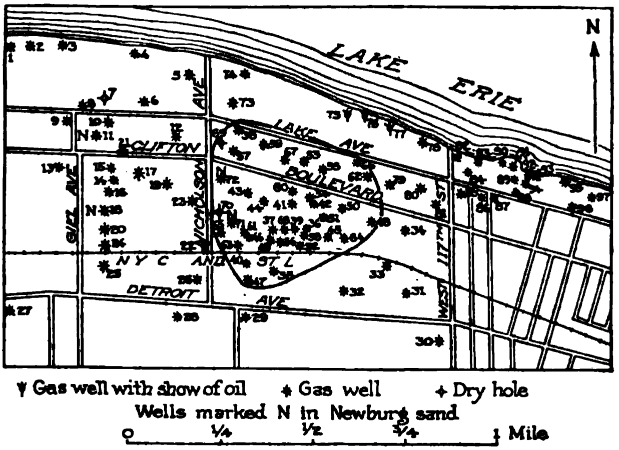

FIGURE 8.—Map of eastern part of Lakewood pool, Cleveland, Ohio. Statistics of wells in area inclosed by line (referred to as the Lakewood group) are given in the table on page 46 and in figures 9 and 11.

Statistics of the wells are given in the accompanying table.

Statistics of wells in Lakewood group, on Clifton Boulevard east of Nicholson Avenue.

No. of well on map (fig. 8).	Date brought in.	Initial rock pressure.	Initial open flow.	Date abandoned.	Life of well.	Depreciation.	
						Period.	Per cent.
	1914.	*Pounds.*	*Cubic feet.*		*Months.*	*Months.*	
35	May 16	950	2,694,000			13	90
36	June 25	890	4,653,000	Nov. 29, 1915	17		
37	July 7	810	4,257,000	Feb. 12, 1915	7		
38	Aug. 5	650	1,979,600	Dec. 18, 1914	4		
39	Aug. 24	490	2,193,000	Mar. 11, 1915	7		
40	Aug. 27	625	2,980,000	Feb. 18, 1916	18		
41	Aug. 28	580	3,258,000				
42	Sept. 9	600	3,465,000	Nov. 29, 1915	15		
43	Sept. 9	515	1,629,000	Jan. 8, 1915	4		
44	Sept. 12	545	1,812,000	Feb. 12, 1915	5		
45	Sept. 15	570	1,554,000	May 13, 1915	8		
46	Sept. 16	500	1,580,000	Mar. 30, 1915	6		
47	Sept. 22	565	3,500,000			9	83
48	Sept. 25	720	2,067,000	Apr. 12, 1916	19	10	95
49	Sept. 27	510	2,125,000			10	88
50	Sept. 29	625	3,617,000			9	92
51	Oct. 1	435	1,245,000			9	89
52	Oct. 3	470	2,304,000	Feb. 19, 1916	17	9	89
53	Oct. 10	290	350,000	Mar. 2, 1915	5		
54	Oct. 12	325	1,759,000	May 29, 1915	8		
55	Oct. 19	460	1,250,000	Apr. 12, 1915	6		
56	Oct. 22	330	2,457,000	Feb. 2, 1915	3		
57	Oct. 29	270	789,000			8	46
58	Nov. 5	215	900,000	Jan. 26, 1915	3		
59	Nov. 10	280	840,000	Mar. 4, 1915	4		
60	Nov. 20		431,000				
61	Nov. 29	205	661,200	Sept. 25, 1915	10		
62	Dec. 9	360	2,000,000	Mar. 15, 1915	3		
63	Dec. 11	225	421,200	Oct. 13, 1915	10	6	67
64[a]	Dec. 22		350,000	Dec. 22, 1914	0		
65[a]	Dec. 28		350,000	Dec. 28, 1914	0		
66	Dec. 30	280	350,000	Sept. 20, 1915	10		
67[a]	Dec. 31		225,000	Dec. 31, 1914	0		
	1915.						
68[a]	Jan. 9		421,200	Jan. 9, 1915	0		
69	Feb. 8		Dry.	Feb. 8, 1915	0		
70	Mar. 8		Dry.	Mar. 8, 1915	0		
Average, 7 wells brought in prior to Aug. 31, 1914.		713	3,150,000				
Average, 16 wells brought in between Sept. 1 and Oct. 31, 1914		483	1,970,000				
Average, 13 wells brought in after Nov. 1, 1915		205±	600,000±				

[a] Plugged and abandoned.

The decline of initial pressure is shown in figure 9. The first well had an initial pressure of 950 pounds, and later wells showed increasingly lower pressures. Four wells finished six months later averaged 267 pounds, but of the last seven wells drilled two were reported as dry and four had pressures so small that they were immediately abandoned. Comparison of the curves showing well drilling and decline in pressure indicates plainly that the period of greatest decline was that in which the largest number of wells were brought in.

Despite the considerable number of wells involved their initial pressures fall close to the average shown by the curve sketched in figure 9. Wells 48, 62, and 66 started at pressures somewhat above the average, which is explained by their distance from the wells previously drilled. The abnormally low pressure of well 39 is presumably due to the fact that it is only a few hundred feet from

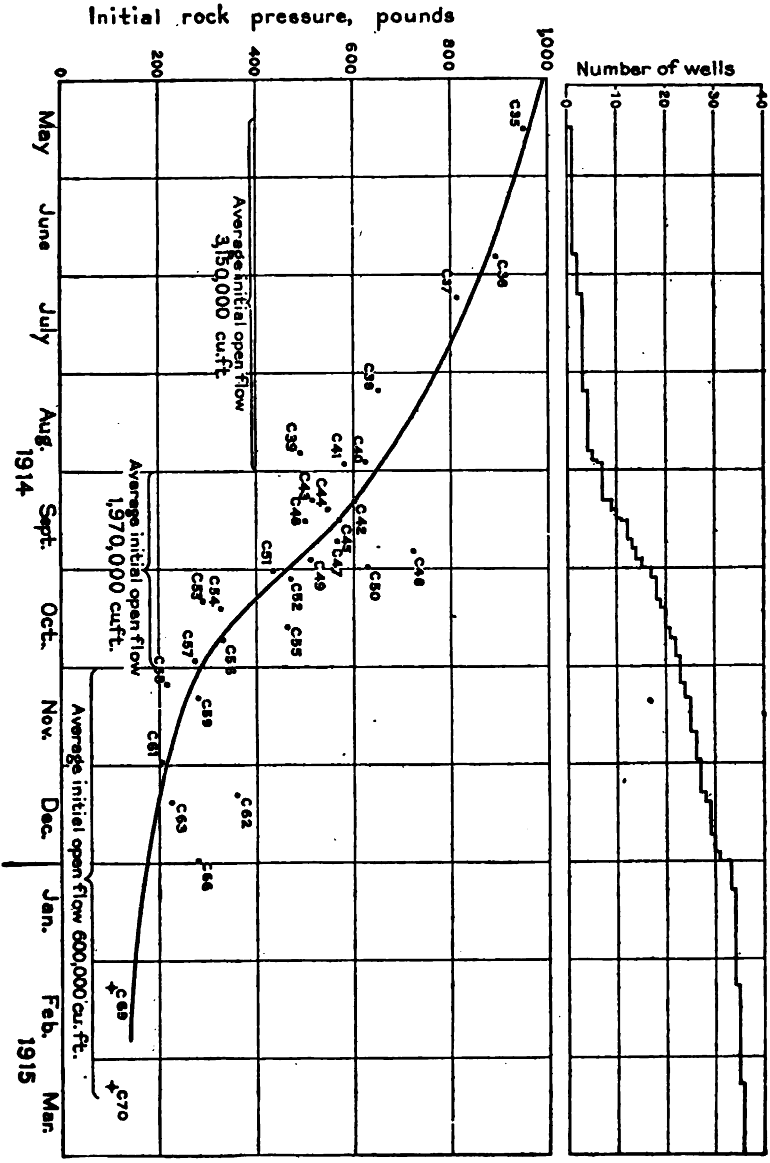

FIGURE 9.—Sketched curve showing average decline in initial rock pressure of wells in Lakewood group, Cleveland, Ohio. C35, C36, etc., refer to wells 35, 36, etc., in figure 8.

an earlier well, No. 36. All the later wells except Nos. 62 and 66 were drilled close to wells that had been producing for some months, and their initial pressures and flows were therefore very low.

RATE OF DECLINE OF PRESSURE IN RELATION TO ACREAGE.

The initial pressures of several other groups of wells have been tabulated by the writer, but a detailed presentation of the results would be merely repetition of the figures and the curves already discussed. Providing the area involved is not over 150 acres and the sand is productive throughout, the initial pressures decline on a fairly regular curve, which is believed to be essentially similar to and only slightly higher than the curve for decline in pressure during the life of individual wells.

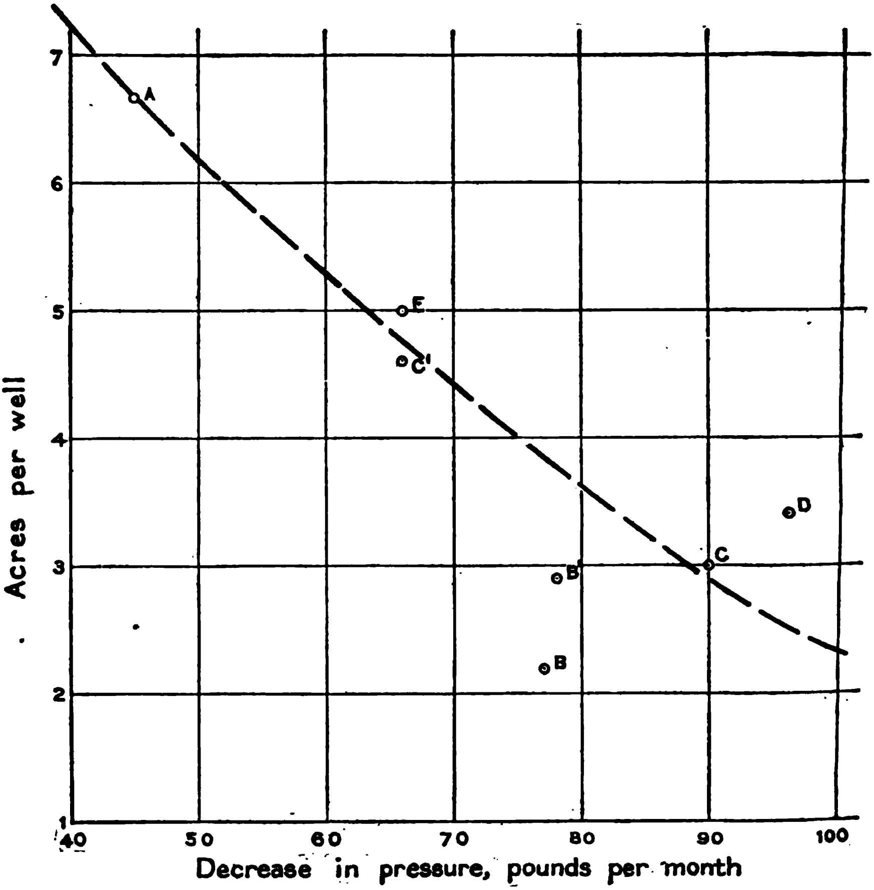

FIGURE 10.—Diagram showing relation of rate of decline of rock pressure to acreage per well in Cleveland field, Ohio. Points represent groups of wells in various parts of field, as follows: A, Rockport group, 12 wells; B, West Park group, 29 wells near Vinton Row; B', 32 wells near Lorain Avenue and Bunts Road; C, Lakewood group, 32 wells east of Nicholson Avenue; C', 11 wells west of Nicholson Avenue; D, Brooklyn group, 25 wells; E, 18 wells at Puritas Springs and Harrington roads. (Curve shown is sketched, not computed.)

That the rate of decline in pressure depends on the rate at which the gas is removed is shown by the fact that in each area the period of greatest decline was that in which the largest number of wells were brought in. As the rate at which gas is removed depends in a broad sense on the number of wells per unit area, the average rate of decline in pressure would be expected to vary with the acreage per well. Accordingly in each of the groups studied the difference between the initial pressures of the first and last wells was divided by the number of months in order to arrive at the average decrease in pressure per month. These figures, with the acreage per well in each group, are plotted in figure 10.

The points plotted in this figure indicate a distinct relation between the rate of decline in pressure and the acreage per well. Some irregularities are to be expected, for the minor factors influencing the rate of decline in pressure are very complex and include the relations of the group to neighboring wells, the capacities of the wells represented, and the relation of the period of greatest drilling to the whole period considered. These subordinate factors are minimized, however, by the fact that seven groups in different parts of the field, comprising in all 159 wells, are represented. There is therefore no question as to the general correctness of the relations shown, and it may confidently be asserted that if the Lakewood group had consisted of only 15 or 18 wells instead of 36 the pressure would have declined only about half as rapidly.

It is unfortunate that data are not available to show the rate of decline in pressure with an area of 40 acres or more to the well, for the figures of acreage used are lower than those in most gas fields, and as the curve can not be extrapolated without more data it can not be directly applied in many other areas. It is evident that the curve for higher acreages would be much steeper and that a small difference in acreage would have less effect on the rate of decline in pressure. It is also probable that many minor factors would become more prominent and introduce more irregularities, though the same general relation would undoubtedly hold.

RELATION OF ROCK PRESSURE TO FLOW.

OPEN FLOW.

The decline of initial rock pressure has been discussed in some detail because the data are fairly complete. Its relation to the decline in flow is of more direct economic interest. It has already been pointed out that the volume of flow is greatly influenced by the porosity of the sand; where the sand is tight a well yielding a very small flow may register a high pressure. On the other hand, however, a large flow is usually associated with a high pressure. If the gas were contained in a tank or reservoir, or if the sand were entirely uniform in porosity, there would be a direct and definite relation between pressure and flow. As a matter of fact, if the sand has a

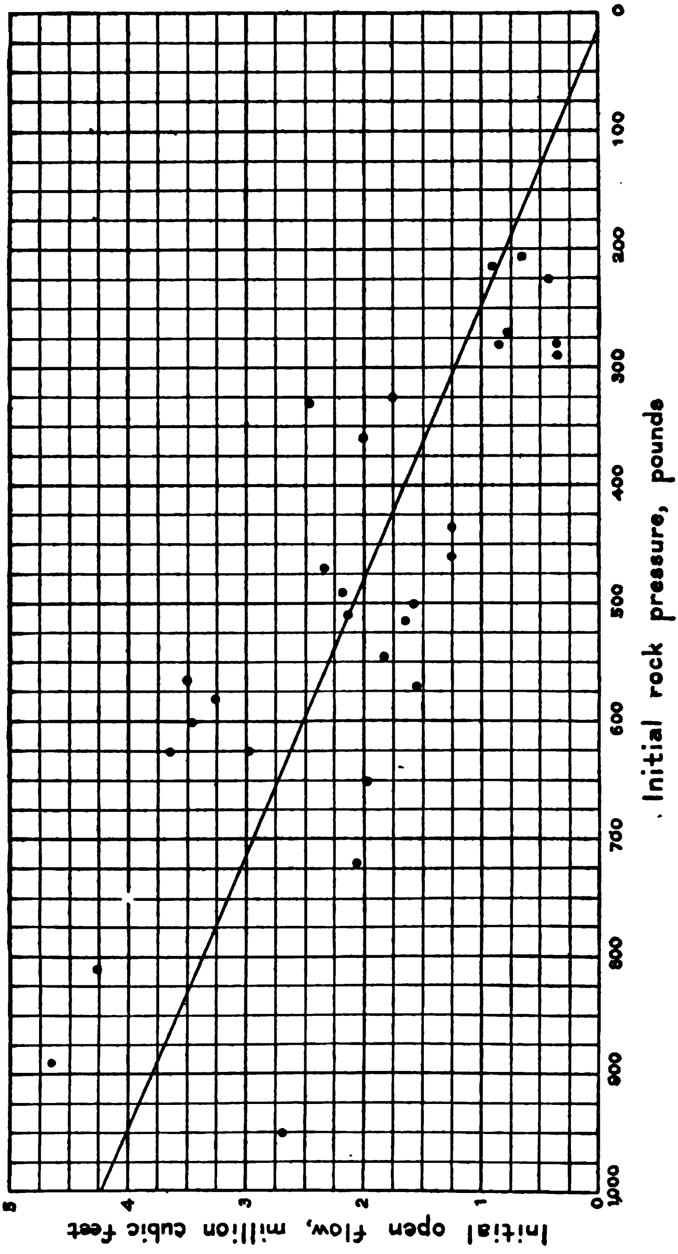

FIGURE 11.—Curve showing decrease in initial open flow with decrease in initial rock pressure in 29 wells in Lakewood group, Cleveland, Ohio. (See figs. 8 and 9 and table, p. 46.) Curve shown is computed from formula 8, page 51.

fairly uniform porosity under a given area and if a number of wells sufficiently large to eliminate the minor variations are considered, it is found that there is a definite average relation between pressure and flow, from which, however, individual wells may show wide variation.

In order to show the relation between pressure and flow the 29 wells in the Lakewood group have been selected, because these wells are believed to be typical and because the data concerning them are more nearly complete than those concerning other groups. The initial rock pressure and initial open flow of these wells are given on page 46 and are plotted in figure 11. It will be noted that the pressure and flow are roughly proportional and that the curve shown is a straight line.

C. E. Van Orstrand, who computed the curve, discusses methods of representing the relations of flow and pressure as follows:

The following empirical formulas have been used to represent the relation between discharge and rock pressure:

$$(1)\quad v=0.06100\left[\left(\frac{p}{p_o}\right)^{2.0}-1\right]^{\frac{1}{2}}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(14.6)$$

$$(2)\quad v=0.042328\,(p-p_o)^{\frac{1}{2}}+0.00010186\,(p-p_o)^{\frac{3}{2}}\ldots\ldots\ldots\ldots\ldots\ldots(14.9)$$

$$(3)\quad v=0.004289\,(p-p_o)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(14.5)$$

$$(4)\quad v=0.004269\,(p-p_o)+0.000000032\,(p-p_o)^{2}\ldots\ldots\ldots\ldots\ldots\ldots(14.5)$$

$$(5)\quad v=0.004876\,(p-p_o)-0.014095115\,(p-p_o)^{\frac{1}{2}}\ldots\ldots\ldots\ldots\ldots\ldots(15.2)$$

In these equations v=volume of gas discharged in 24 hours, p=rock pressure in pounds, p_o=14.6 pounds.

The numbers in parentheses at the right are the sums of the squares of the differences between the observed and computed values of v. On applying the usual least-square criterion that this sum must be a minimum, it appears that there is practically no choice between the first four equations.

The first equation is a simplified form of the theoretical equation used by Robinson[1] to express the volume of discharge (v) as a function of the internal gas pressure (p) and the external pressure (p_o) of the atmosphere into which the gas is discharged. The exponent (n) of the theoretical equation has been retained, but the remaining theoretical constants have been replaced by a single empirical constant. If we designate by γ the ratio of specific heats at constant temperature and volume, we have the theoretical relation

$$n=\frac{\gamma}{\gamma-1}$$

Robinson gives

$$n=3.451\qquad \gamma=1.408$$

whereas our first equation gives

$$n=2.0+\qquad \gamma=2.0-$$

No particular significance is attached to these results, but it is of importance to know that there is no evidence of disagreement between theory and the observed values.

The second equation contains two terms only of Robinson's expansion in infinite series of the theoretical equation. The remaining equations are simply interpolation formulas selected chiefly for the convenience of investigators who may desire to determine analytical expressions for the representation of similar data.

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[1] Robinson, S. W., Measurement of gas wells and other streams and the piping of natural gas: Ohio Geol. Survey Rept., vol. 6, pp. 548–594, 1888. For the theory of efflux of gases, see Lamb's Hydrodynamics, p. 23, Cambridge University Press, 1906.

Figure 11, in connection with the foregoing discussion, shows clearly that, as would be expected, there is a definite relation between the initial rock pressure and the initial open flow of the average well. In applying any of the formulas to wells in other areas it will, of course, be necessary to alter the empirical constants, for in some fields an initial pressure of 1,000 pounds is associated with a flow several times greater than in the Lakewood pool. In other words, the position of the curve varies according to the locality; its form, however, should not vary greatly, and that shown in figure 11 is typical.

The important practical consideration is that the later wells in a pool, having lower initial pressures than the earlier wells, are likely to have smaller flows. The rate of decline in pressure and the relation between pressure and flow are by no means invariable, but in a small pool they may be determined closely enough to permit a calculation, according to the theory of probability, of the flow and pressure of a well brought in on any date. For example, when the rock pressure in the Lakewood pool had declined to 215 pounds, in November, 1914, the chances were about 60 in 100 that the open flow of a new well would be less than 1,500,000 cubic feet and only 1 in 100 that it would exceed 2,750,000 cubic feet. The derivation of these figures and the application of the theory of probability to new wells are discussed in more detail on pages 61–64.

The equations given above indicate further that the decline in pressure during the life of the wells was about proportional to the decline in flow. According to Boyle's law, if the volume of gas remains constant the quantity must decrease about as the pressure decreases, and the rate of decline in pressure is therefore a rather accurate index of the amount of gas remaining in the sand. This conclusion, of course, is based on the assumption that water or oil does not follow up the gas and thus maintain the pressure, a condition which does not seem to exist in the Cleveland field.

FLOW AGAINST LINE PRESSURE (PRODUCTION).

Although the rock pressure and open flow of a well are generally accepted as the indexes of its capacity, the quantity of gas that it delivers into the pipe line is of course the direct measure of its value. In eastern gas fields it is customary to maintain in the pipe line a pressure of 15 to 150 pounds, and this pressure must be overcome by the gas that enters the pipe line from the well. The effective pressure of the well is thus its rock pressure minus the line pressure, and as the volume of flow depends partly on the pressure the delivery into the line is probably always smaller than the open flow, which overcomes only the atmospheric pressure of 15 pounds. This is shown by the following data of well 74 in the Lakewood pool (fig. 8):

Open flow, 2,623,640 cubic feet; rock pressure, 720 pounds.
Delivery into line, 1,977,651 cubic feet; line pressure, 147 pounds.

The open flow of 2,623,640 cubic feet was made with an effective pressure of 705 (720 minus 15) pounds, whereas the delivery of 1,977,651 cubic feet, which is 75.4 per cent of the open flow, was made with an effective pressure of 573 (720 minus 147) pounds. It is evident that when the pressure in this well had declined to 147 pounds, if the line pressure remained constant the flow from the well into the line would cease, though a considerable open flow would still be available. Hence, the lower the rock pressure in a well the smaller is the proportion of the open flow delivered into the line.

Data showing the exact ratio between open flow and flow into the line are unfortunately not available for other wells, but some idea of the relation may be obtained by comparing the initial open flow with the average daily delivery for the first 30 days. This comparison of course introduces another factor of indeterminate value—the decline of flow during the 30 days—and the comparison is therefore really between the open flow on the first day and the flow into the line on the fifteenth day. As the rate of decline is variable, the figures obtained in this way have little quantitative value, but they are of practical interest as showing that few wells deliver daily during the first month more than half their initial open flow. The accompanying table gives the records of as many wells in the West Park and Lakewood groups as are available.

Percentage of initial open flow delivered against line pressure under different rock pressures.

No. of well on map.		Initial open flow, first day.[a]	Average daily delivery during first month.[b]	Per cent of initial open flow delivered daily during first month.	Initial rock pressure.
Fig. 6.	Fig. 8.				
		Cubic feet.	*Cubic feet.*		*Pounds.*
95	....	5,256,000	1,797,000	34	940
....	48	2,067,000	862,000	42	720
99	....	4,098,000	2,201,000	54	700
....	50	3,617,000	912,000	25	625
100	....	6,498,000	2,554,000	39	600
....	47	3,500,000	1,260,000	36	565
134	....	3,823,000	1,982,000	52	560
103	....	4,389,000	2,227,000	51	550
....	49	2,125,000	673,000	32	510
....	52	2,304,000	589,000	26	470
101	....	2,694,000	802,000	30	470
106	....	3,781,000	1,109,000	29	470
102	....	2,494,000	1,130,000	45	440
....	51	1,245,000	437,000	35	435
94	....	879,000	596,000	68	435
104	....	1,902,000	639,000	34	415
107	....	2,500,000	605,000	24	350
108	....	1,554,000	417,000	27	325
135	....	1,760,000	375,000	21	305
....	57	789,000	119,000	15	270
....	63	421,000	81,000	19	225
141	....	1,048,000	339,000	32	220

[a] Against atmospheric pressure (15 pounds).
[b] Against line pressure (140 to 150 pounds).

In figure 12 the percentage figures given in the fourth column of this table are plotted with the initial rock pressure; and it will be noted that there is a distinct relation between the two. When the rock pressures are high there is apparently little variation in the delivery, but as the rock pressure declines the delivery drops off sharply. In other words, wells brought in after the rock pressure has declined to 300 pounds or so not only are likely to have small open flows but they can not deliver as large a percentage

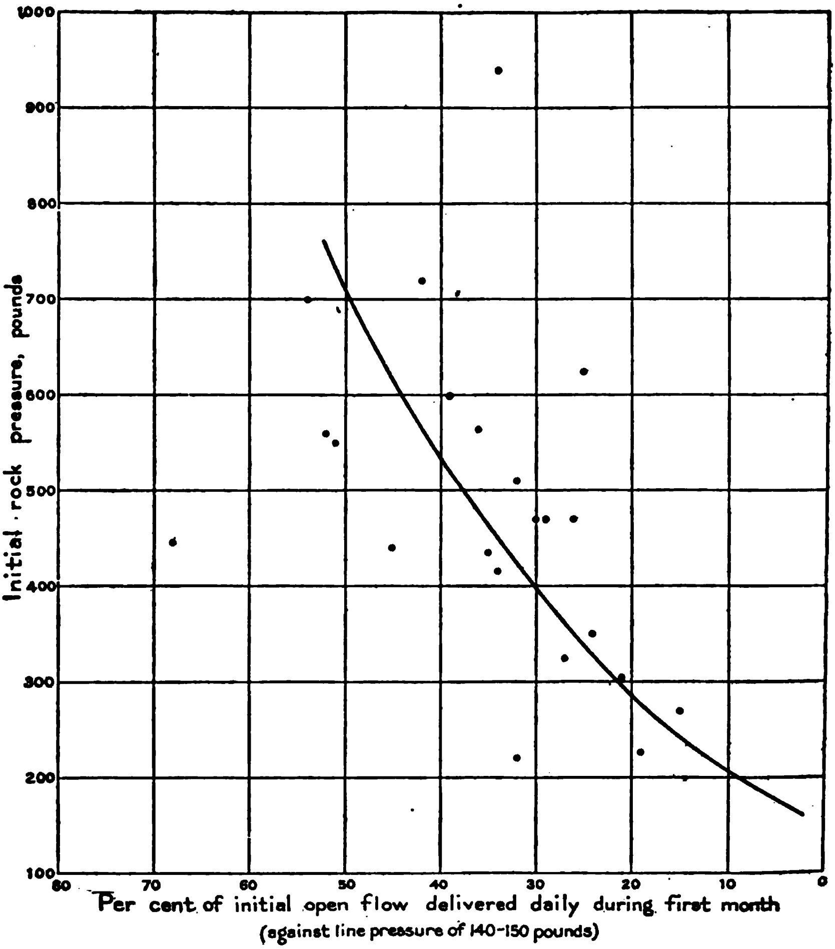


FIGURE 12.—Sketched curve showing decrease in percentage of open flow delivered into pipe line (against pressure of 140 to 150 pounds) with decreasing rock pressure, Cleveland field, Ohio. The percentage figures were obtained by dividing the average daily delivery during the first month by the initial open flow and therefore take into account the normal decline of the well during the first 15 days. (See table, p. 53, and text.) They are 10 to 25 per cent lower than figures representing open flow and delivery on the same day, but they show plainly that the discrepancy between open flow and actual delivery is especially large in wells having low rock pressure.

of their open flow as the earlier high-pressure wells can. This consideration reduces still further the probable financial returns from the average late well.

DECLINE OF PRODUCTION.

WEST PARK GROUP.

As the volume of open flow depends chiefly on the rock pressure, a general idea of the decline in the flow of wells in various parts of the field may be obtained from the records of decline in pressure already given. These figures can not be translated directly into statistics of production, however, because with a constant line pressure the quantity of gas delivered by the well decreases faster than the rock pressure or the open flow.

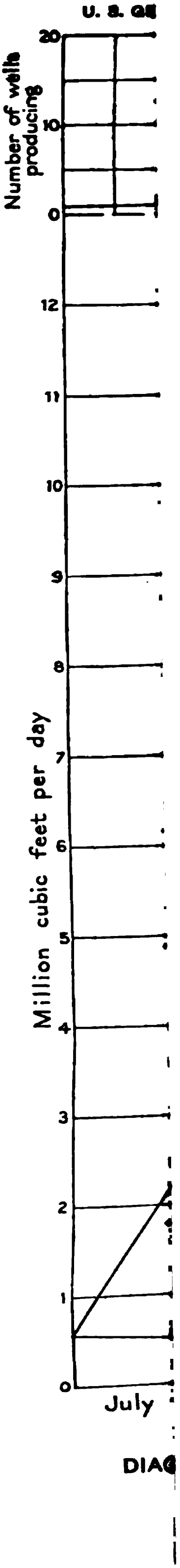
Though detailed records of the decline of individual wells are not available, measurements of the total decline in a given period have been determined for a number of wells. These figures, expressed as percentages, are given in the columns headed "Depreciation" in the foregoing tables. As records of the decline of all the wells in the southern district of the West Park group are available the decline in that group may be considered in detail. (See table, p. 43.)

In Plate II the average daily delivery of each well during its first month and during July, 1915, are plotted, and the two points thus obtained for each well are connected by a straight line. The line represents the total decline of the well for the period involved, and is therefore a summary of the detailed decline curve. The curve showing by months the total production of the group was then constructed by adding the average daily delivery of each well. A curve showing the number of wells producing each month is also given at the top of the diagram.

The most striking feature shown by the diagram is the general uniformity in the rate of decline of individual wells. Two of the earliest wells brought in were small and soon became exhausted, but the remaining wells drilled in 1914 started with fairly large flows. With one exception all of the wells brought in during 1915 were moderate or small, but as they declined at about the same rate as the earlier ones the daily production of all wells on July 31 approximated the same figure. In other words, the earlier wells in the group obtained the "flush" production; the later wells, starting with smaller flows and declining at the same rate, were about as nearly exhausted on July 31 as the wells that had been producing considerably longer. The writer has no exact information as to the rate of decline after July 31, but it is well known that the rate decreases toward the end of the life of the wells and that a small production may be maintained for many months. Thus well 104, which had declined 95 per cent by July 31, 1915, was not abandoned until March 14, 1916, and well 105, which had declined 80 per cent by July 31, 1915, continued to produce a little until January 24, 1916.

Although most of the wells whose decline is shown in Plate II declined at a fairly uniform rate, a few departed rather widely from the average. These variations are doubtless due chiefly to differences in the percentage of time that the wells were producing. This factor is particularly important with respect to gas wells, because it varies greatly with the season, the demand for gas being much greater during the winter. Many wells in the Cleveland field that produce practically 100 per cent of the time during the winter are closed more than 50 per cent of the time during the summer, and as the life of a gas well is generally short compared with that of an oil well this seasonal fluctuation has a correspondingly greater effect on the curve of decline in production. In compiling Plate II the production of the wells was divided by the percentage of time that they produced in order to obtain comparable figures representing as closely as possible their maximum capacity. Although this is the simplest method of standardizing the figures it is not wholly satisfactory in representing the decline, for a well producing only 10 per cent of the time would decline more slowly than one producing continuously. Most of the wells represented in the diagram were brought in before or during the winter, and were therefore operated almost continuously for some time, but wells 107 and 108 did not begin to produce until spring. Well 107 was allowed to flow only 38 per cent of the time during the first month and only 14 per cent during July, and its decline curve is therefore much flatter than that of any earlier well.

The aggregate production of the whole group attained its maximum on February 1, and it is interesting to note that the added production of the four wells completed after that date did not suffice to prevent a steady and rapid decline in the production of the group. As the number of wells per unit area has much to do with the rate of decline in pressure and therefore with the rate of decline in production, it is evident that if the four last wells had not been drilled the production of the earlier wells would not have declined so rapidly. With one possible exception none of the four last wells produced enough gas to pay for itself; these wells served merely to shorten the life of the earlier ones. As a matter of fact the records of decline in pressure given in figure 10 indicate that one or two wells would have been able in two or three years to drain all the gas from the area under consideration, and that the remaining 13 were therefore unnecessary; but Plate II shows clearly the loss entailed by rilling at least the last four.


U. S. G
Number of wells producing
20
10
0
Million cubic feet per day
12
11
10
9
8
7
6
5
4
3
2
1
0
July

DIAG

AVERAGE DECLINE OF WELLS IN THE CLEVELAND FIELD.

In order to obtain a more representative and detailed curve of the decline in production the records of over 350 wells have been compiled as a basis for the composite curve shown in figure 13. These wells include more than three-fourths of all those that produced gas prior to July 1, 1915, but it should be noted that most of them are in the thickly drilled Lakewood and West Park districts, where the decline is undoubtedly more rapid than in the recently developed territory to the south. The figures on which this curve are based are of the same kind as those just considered, and represent a comparison of the first month's production of each well with its production during July, 1915, the latter being expressed as a per-

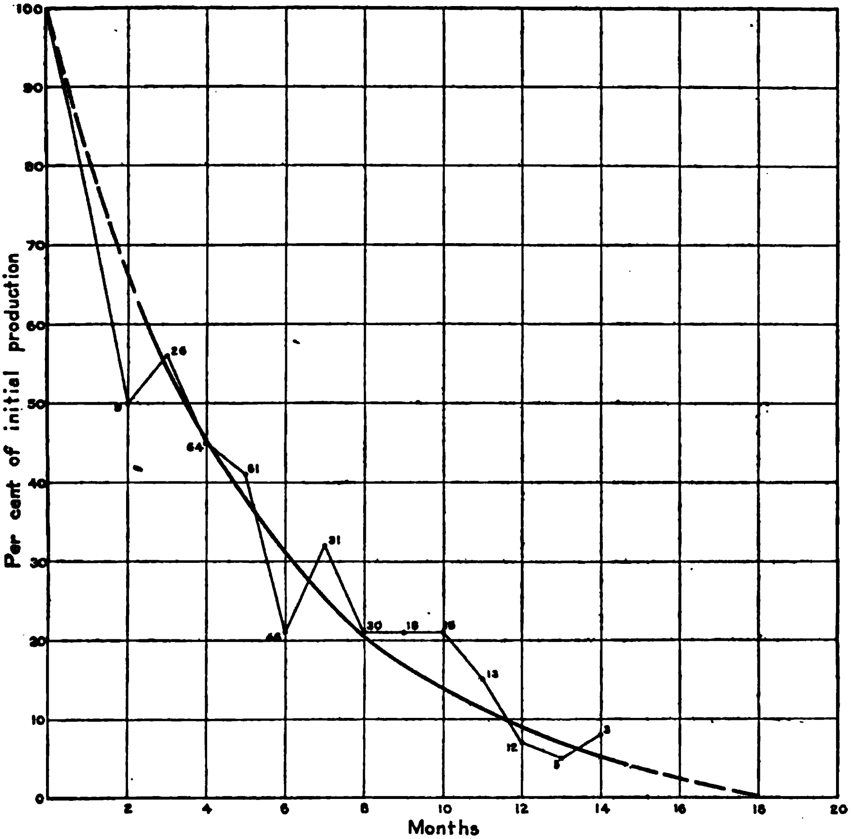


FIGURE 13.—Diagram showing average decline in production of over 350 wells in the Cleveland field, Ohio (mostly in the Lakewood and West Park pools). Points represent average decline of different groups of wells for different periods; sketched curve may be considered a generalized representation of the decline of the average well.

centage of the former. In this way the average decline of a number of wells during a period of two months, of a number of others during a period of three months, and so on, were obtained. Wells that had been abandoned before July 31 were also included; the decline of a well abandoned at the end of three months, for example, was taken as 100 per cent and averaged in with those of the wells that started to produce three months prior to July 31. The following table shows the average decline at the end of each month from the 2d to the 20th and also the approximate number of wells entering into each average:

Decline in production of wells in Cleveland field.

Month.	Number of measuring stations averaged.[a]	Per cent of first month's production.	Month.	Number of measuring stations averaged.[a]	Per cent of first month's production.
Second	9	50	Twelfth	12	7
Third	26	56	Thirteenth	5	5
Fourth	64	45	Fourteenth	3	8
Fifth	61	41	Fifteenth	1	14
Sixth	46	21	Sixteenth	2	7
Seventh	31	32	Seventeenth	2	11
Eighth	30	21	Eighteenth	2	16
Ninth	18	21	Nineteenth	1	9
Tenth	18	21	Twentieth	1	11
Eleventh	13	15	Thirty-fifth	1	13

[a] In general one measuring station represents one well, but a few stations include the gas from several neighboring wells.

The records of a fairly large number of wells enter into the average for each month from the 2d to the 12th, but the averages for longer periods are based on the records of so few wells that they can not be considered reliable. One well, for example, produced 13 per cent in the thirty-fifth month, though 12 wells averaged only 7 per cent in the twelfth month. Accordingly only the averages up to the fourteenth month were taken into account in sketching the average curve shown in figure 13.

Despite the many factors that cause one well to decline more rapidly than another, the figures up to the twelfth month are reasonably concordant, and, as the curve shown is based on the records of nearly all the wells that produced prior to July 1, 1915, and as these wells came in at different times and with different pressures and flows, it may be regarded as representing in a general way the decline of the older part of the field. It is also believed to be fairly representative of the decline of the average well in any district drilled as closely as the older part of the Cleveland field.

LIFE OF WELLS.

The life of a gas well depends primarily on the rate of decline of the flow and pressure, and as the flow and pressure decline at much the same rate in all the wells in a small pool; the last wells drilled will evidently be shorter lived than the earlier ones. If the sand were uniformly porous throughout the area and the wells were finished and operated in the same way they would all reach the point of abandonment at the same time. These conditions are seldom found, however; and, furthermore, economic considerations dictate the abandonment of some wells sooner than others. The statistical tables on the preceding pages show the dates on which many of the wells were abandoned, and it will be noted that the length of the productive period varied greatly. A number of wells became exhausted in three or four months; others produced for two years; one or two have lasted more than three years and are still producing. The exact date on which a well is abandoned is of little importance, for figure 13 indicates that in this field, in general, over 80 per cent of the total production of the well is obtained during the first 12 months, though it may continue to produce a little for a year or so.

On June 1, 1916, 855 gas wells had been drilled and at least 325, or 38 per cent, had been abandoned. The life of the average well in the most thickly drilled parts of the field is probably about 12 months, but the average well in the districts now being developed should produce for several years. The decline curve shown in figure 13, which is based on the records of wells in the most crowded and the moderately crowded parts of the field, indicates that the life of the average well in those districts is about 18 months.

DECLINE OF ROCK PRESSURE AS A GUIDE IN NEW DEVELOPMENT.

FACTORS IN DETERMINING THE PROPER ACREAGE PER WELL.

One of the most important problems confronting the gas-producing industry is that of determining the smallest number of wells capable of removing all the gas from under a given tract of land in the most economical manner possible. So many complex factors enter into this problem that few systematic attempts have been made to solve it, and gas operators have in general been content to accept rough estimates of the number of wells that should be drilled per unit area. In some localities it is held that only one well should be drilled to each 800 acres, although in others it is customary to drill a well in each 20 or 40 acres. With present knowledge this must be to some extent a matter of opinion, but it is very doubtful if any limit can be chosen that will be applicable in all gas fields, for the acreage required will vary according to the structure of the field, the porosity and thickness of the sand, and the relation of the gas to water.

In practice the problem is further complicated by economic factors, important among which are the price of gas and the size of the parcels in which the land is held or the number of companies operating in the field. It is evident that one operator controlling a large acreage and not subject to sharp competition is in a position to develop his territory more economically than a number of operators, each controlling a small tract of land and each endeavoring to produce gas before his neighbor. Only a few fields in the United States are controlled entirely by single operators, and the question as to the best procedure in those fields need not be considered here. There are many fields, however, that have been developed by a number of small companies, and in such fields the tendency is always to drill a larger number of wells than is necessary or profitable. This tendency is so strong that in some places wells have been drilled after the field has become so nearly exhausted that the new wells can not possibly produce enough gas to pay for the cost of drilling.

In the Cleveland field the tendency to drill too closely is strikingly exemplified and has led to considerable financial loss. On June 1, 1916, there were 1,009 wells and dry holes in the field, representing an expenditure for drilling alone of about $5,500,000. The total production of the field to January 1, 1916, was about 50,000,000,000 cubic feet, and the decline curves given warrant the belief that no more than 40,000,000,000 cubic feet will be obtained in the future. If the total production of the 1,009 wells is assumed to be 90,000,000,000 cubic feet, the total value of the gas produced, at 6 cents a thousand, the price paid by the East Ohio Gas Co., is only $5,400,000, or $100,000 less than the outlay for drilling expenses alone. If royalties and ordinary producing expenses are also considered, this operators' deficit is increased many times.

There are some operators in the Cleveland field, however, who have made money, and they are in general the owners of the earliest wells in a given locality. Practically none of the wells brought in after the local rock pressure had declined to a third of its original amount produced enough gas to pay for themselves, and few of the wells drilled after the pressure had declined one-half were profitable. As shown by the figures already given, this is due to the facts that the later wells, having lower initial pressures, generally have smaller initial open flows; that as their pressures are lower they deliver a smaller percentage of their open flow into the pipe line; and that they decline about as rapidly as the older wells, and their productive period is therefore shorter.

It is evident that there is a point in the development of any pool after which new wells drilled will not produce enough gas to be profitable; and as the tendency to overdrill is by no means confined to the Cleveland field, it is important to determine this point for the benefit of operators in general. In the writer's opinion a study of the rate of decline in pressure furnishes an excellent basis for determining the point at which new drilling should cease. From that rate the probable initial open flow of a new well can be estimated and from the decline curve of the average well (such as that shown in fig. 13) the probable total production of the well can be roughly ascertained. It will then be a simple matter to determine the value of this probable total production and to balance it against the cost of drilling and producing. This method is of course based largely on the theory of probability and may not give results precise enough to be of practical value in specific instances, but it is at least more rational than a rough guess as to the number of acres that should be allowed for each well.

APPLICATION OF THE THEORY OF PROBABILITY IN ESTIMATING THE CAPACITY OF A NEW WELL.

By C. E. Van Orstrand.

The formulas given on page 51 indicate that there is a definite and direct relation between the initial rock pressures and initial open flows of the wells in the Lakewood group. There is undoubtedly an equally definite relation between the initial pressures and open flows of the wells in any small group in any field; but in applying the formulas in other areas it would, of course, be necessary to change the empirical constants shown. The formulas in their present form therefore apply to the wells in the Lakewood group, but they are also susceptible of an entirely different application. They may be used to determine the probability that a well brought in with a given initial rock pressure will have an initial open flow falling between certain given limits; or, if the rate of decline in pressure is known, they may be used to determine the probable open flow of a well brought in on a given day. In other words, the differences between the observed points and corresponding points on the straight line (fig. 11) may be treated as residuals in the theory of errors. To use the theory of probability as a basis for estimating the capacity of a new gas well is just as rational as to use it as a basis for fixing life insurance premiums, though in practice the data are fewer, and the method will therefore be somewhat less precise.

In the following calculations the term discharge is used as synonymous with open flow. It is stated in millions of cubic feet, so that a discharge of 0.5, for example, means 500,000 cubic feet per 24 hours.

Let v_o=observed discharge.
v_c=computed discharge.
v_o-v_c=residual.
N=number of observed values.
r=probable error of observation of weight unity.

The quantity r is then given by the well-known least-square equation:

$$r=0.6745\sqrt{\frac{\Sigma\,(v_o-v_c)^2}{N-1}}$$

The following table, which is based on 29 pairs of measurements of pressure and discharge in the Lakewood group, contains all of the quantities needed for the evaluation of r. (See table, p. 46.) The values of v_c were computed from formula 3 (p. 51), which is represented by the straight line in figure 11.

Comparison of observed and computed values of discharge (v) in relation to pressure (p) for wells in Lakewood group.

p	v_o	v_c	(v_o-v_c)	p	v_o	v_c	(v_o-v_c)
950	2.694	4.012	−1.318	625	3.617	2.618	+0.999
890	4.653	3.755	+ .898	435	1.245	1.803	− .558
810	4.257	3.412	+ .845	470	2.304	1.953	+ .351
650	1.980	2.725	− .745	290	.350	1.181	− .831
490	2.193	2.039	+ .154	325	1.759	1.331	+ .428
625	2.980	2.618	+ .362	460	1.250	1.910	− .660
580	3.258	2.425	+ .833	330	2.457	1.353	+1.104
600	3.465	2.511	+ .954	270	.789	1.095	− .306
515	1.629	2.146	− .517	215	.900	.860	+ .040
545	1.812	2.275	− .463	280	.840	1.138	− .298
570	1.554	2.382	− .828	205	.661	.817	− .156
500	1.580	2.082	− .502	360	2.000	1.482	+ .518
565	3.500	2.361	+1.139	225	.421	.902	− .481
720	2.067	3.026	− .959	280	.350	1.138	− .788
510	2.125	2.125	.000				
					$\Sigma\,(v_o-v_c)^2=14.497$		

By substituting in the equation above the values $N=29$ and $\Sigma(v_o-v_c)^2=14.50$, we get

$$r=\pm0.49$$

To interpret the meaning of r, two lines may be drawn parallel to the straight line in figure 11, the one 0.49 unit above, the other 0.49 unit below the computed line. Then it is an even chance, or the probability is 0.5, that an observed point selected at random falls between these limits. In other words, one-half of the observed points should be included in the area between the two parallel lines. Similarly, one-half of the values of (v_o-v_c) given in the foregoing table should be less in numerical magnitude than 0.49.

In order to apply this method to a particular case, let it be required to find the probability that the discharge of a well under a given initial rock pressure will fall between certain prescribed limits. For example, reference to the table on page 46 or to figure 9 shows that well 58, brought in November 5, had an initial pressure of 215 pounds and a flow or discharge of 900,000 cubic feet. Let it be assumed for the moment that the initial pressure of this well is known or has been correctly estimated from the curve of decline in pressure, and let it be required to find the probable flow or discharge at this pressure. The 23 wells brought in prior to November 5 furnish 23 pairs of observed values of the relation of flow and pressure. From these data may be found by least squares (or by graphic methods) the equation

$$v=0.00432\ (p-p_o)$$

which differs but slightly from the equation derived from all 29 observations and represented by formula 3. The value of r then becomes 0.52 instead of 0.49. The close agreement of the two constants shows that sufficient data were at hand on November 5 to extend the line slightly beyond the points representing all the observations that had been made at that time. Assuming the possibility of this extension and substituting $p=215$ in the last equation we have

$$v=0.87 \text{ (or 870,000 cubic feet).}$$

The following table gives the probability (P) that the discharge (v) of a well in the Lakewood group, having an initial rock pressure on November 5 of 215 pounds, will fall between the limits $0.87+x$ and $0.87-x$. The ratio $\frac{x}{r}$, being equal to 0.52, is the argument used in the evaluation of P from tables of the probability integral.[1]

Probability that the discharge of a new well having an initial rock pressure of 215 pounds will fall within certain limits.

Range of v (millions of cubic feet).	x	$\frac{x}{r}$	P
Between 0.74 and 1.00	0.13	0.25	0.14
Between 0.49 and 1.25	.38	.73	.38
Between 0.24 and 1.50	.63	1.21	.59
Between 0.00 and 1.74	.87	1.67	.74
Greater than 2.00	1.13	2.17	.14
Greater than 2.75	1.88	3.62	.01

The table shows that there were 14 chances in 100 that the discharge of a well in this group, possessing an initial rock pressure of 215 pounds, would fall between the limits 0.74 and 1.00, conversely that there were 86 chances in 100 that the discharge would be less than 0.74 or greater than 1.00. Similarly, the chances were 59 in 100 that the discharge would fall between 0.24 and 1.50, and only 41 that it would fall outside of these limits. The last value in the table shows that there was only 1 chance in 100 that the discharge would exceed 2.75.

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[1] See, for example, Merriman, Mansfield, Method of least squares, Table II.

In the foregoing example it was assumed that the initial pressure of the new well was known to be 215 pounds. As a matter of fact, however, this figure could be obtained only by extrapolating the curve of decline in pressure, and the determination of the probable pressure of a new well is therefore also subject to the law of probability. The following table is based on time and pressure instead of on pressure and discharge. It gives the probability (P) that a well drilled on November 5 would have a rock pressure (p) within given limits. The values $r=0.52$, and $p=270$, which were used in computing the table, are based on the curve sketched in figure 9.

Probability that the rock pressure of a well brought in November 5 would fall within certain limits.

Range of p (pounds).	x	$\frac{x}{r}$	P
Between 240 and 300	30	0.58	0.80
Between 190 and 350	80	1.54	.70
Between 140 and 400	130	2.50	.91
Between 90 and 450	180	3.46	.98

In the first example given discharge or flow was computed as a function of pressure, and in the second pressure was computed as a function of time. It is evident that a third method is possible, wherein discharge is computed or plotted as a function of time. By this method the probability that the initial flow of a well brought in on a given date will fall within given limits may be determined directly.

VALUATION OF A WELL FROM ITS INITIAL PRESSURE AND FLOW.

In the foregoing examples Mr. Van Orstrand has demonstrated the practicability of estimating the probable initial pressure or flow of a new well from the initial pressures and flows of the earlier wells in the group; it now remains to consider briefly the valuation of a well on the basis of its initial performance, as thus estimated. The first example given above indicates that a well drilled in November, 1914, in the Lakewood group and having an initial pressure of 215 pounds should theoretically (according to the data available at that time) have an initial flow of 870,000 cubic feet; that the chances were about 60 in 100 that the flow would not exceed 1,150,000 cubic feet; and that there was only 1 chance in 100 that the flow would exceed 2,750,000 cubic feet. As an extreme case let it be assumed that the smallest chance is accepted, and that it is desired to determine the value of a well having an initial flow of 2,750,000 cubic feet and a pressure of 215 pounds.

The first problem is that of expressing the production of the well in terms of open flow. Welch,[1] in discussing the wells of the Petrolia field, Tex., says:

> There are no definite mathematical formulas for determining in terms of open-flow capacity the amount of gas that can be taken from wells. The amount depends, however, on the character of the sand and the pressure of the gas within it, the pressure on the pipe line at the mouth of the well, and this in turn depends on the pressure at the intake of the compressor station, on the size of casing and of the lines from the wells to the station, and the total amount of gas being delivered. An empirical figure of 25 per cent of the open-flow capacity, which is frequently used, is as high as is safe to expect.

This statement is borne out by the sketched curve in figure 12, which shows the relation between the initial open flow of 22 wells and their average daily delivery during the first month. With a line pressure of 150 pounds, a well having a rock pressure of 215 pounds would apparently deliver daily during the first month an average of only about 12 per cent of its initial open flow. The delivery of this well on the first day would of course be higher and might reach 25 or 35 per cent of the open flow. These data are hardly sufficient to warrant a definite conclusion, however, and for the present purpose the empirical figure of 25 per cent used by Welch may be adopted.

In order to estimate the total production of a well from its production on the first day, it is necessary to use a curve showing the decline of a number of wells whose geologic and technologic features are not widely different from those of the well under consideration. In the absence of a detailed curve of this kind the curve shown in figure 13 may be used. The total content of this curve is 144—that is, the average well producing 1,000,000 cubic feet on the first day will produce a total of 144,000,000 cubic feet in the course of 18 months, at the end of which it will be exhausted. In the case under consideration the initial open flow is assumed to be 2,750,000 cubic feet and the first day's production 25 per cent of this, or 687,500 cubic feet. The total production of this well will then be 687,500 times 144, or about 99,000,000 cubic feet. At 6 cents per thousand cubic feet the value of this gas is about $5,950. In the Cleveland field this figure barely suffices to cover the cost of drilling, without considering royalties or producing expenses, and the well will therefore presumably be a financial loss. When it is recalled that there is only 1 chance in 100 that the open flow of the well would be as high as the figure chosen, it is evident that there was practically no likelihood that the well could produce enough gas to pay even the cost of drilling.

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[1] Welch, W. M., The natural-gas resources and supplies of northern Texas and southern Oklahoma (unpublished report to Bureau of Mines, 1916).

GENERAL APPLICATION OF THE METHOD OUTLINED.

The method of estimating the probable value of a new well outlined in the preceding pages is believed to be entirely practicable and should be of service in many fields. The accuracy of the results will of course depend on the amount of information at hand concerning the initial flow and pressure and the rate of decline of other wells in the same locality. However, in order to ascertain whether or not a well is likely to pay it is not necessary to determine its exact value, but merely to estimate whether the probable value of the gas produced (after deducting royalties) is greater or less than the cost of drilling and producing. If the probable value of the well is found to be little more than its cost the well should not be drilled, for there are in general a sufficient number of hazards in the gas-producing industry to necessitate a considerable margin of profit.

It should be reiterated that the curves and formulas in the preceding pages are given here as simply illustrating methods susceptible of general application. They are based wholly on wells in the Cleveland field and can not be applied directly in other fields unless there is good evidence that the geologic and technologic conditions in such fields are similar to those at Cleveland. For example, in the case discussed above it was shown that a well in the Lakewood group having an initial pressure of 215 pounds would probably not produce enough gas to pay for itself; but in some fields a pressure of 215 pounds may be associated with a flow of more than 5,000,000 cubic feet and the well might be highly profitable. The absolute figures doubtless vary greatly, but it seems probable that if the ratio of the pressure of the well to the original pressure of the pool is considered, a more constant criterion may be established. Thus it is safe to state that few if any wells in the Cleveland field brought in after the local pressure had declined to one-third of its original amount were profitable, and there is reason to suppose that this generalization will apply in many if not in most other gas fields. In the Cleveland field a majority of the wells finished after the local pressure had declined one-half were probably also unprofitable, but how widely this figure can be applied in other fields is at present largely a matter of conjecture. It is probable, however, that in nearly all fields the critical point in the decline in pressure, below which new wells are likely to be unprofitable, ranges between 65 and 25 per cent of the original figure. It is to be hoped that this line of investigation will be followed further, for it is obvious that the determination of a general critical limit for all fields, or at least for all fields of the same geologic type, would be of great value to the gas-producing industry.

In order to estimate the probable value of new wells on the basis of declining rock pressure, certain data relating to other wells in the same area or in one that is similar geologically are essential. For the convenience of those who may desire to pursue this line of investigation the necessary information may be tabulated, as follows:

1. The date of completion, the initial rock pressure, and the initial open flow of a number of wells. These wells should preferably be located in an area in which the sand is fairly homogeneous and in which the pressure declines at a fairly uniform rate.
2. The rock pressure and open flow of a number of wells and their delivery into the pipe line on the same day against known line pressure.
3. The rate of decline in the production of a number of wells under normal operating conditions. These records should preferably cover the whole period from inception to exhaustion, but, as a large part of the total production of a well is obtained during the first half of its life, the decline curve may be extrapolated without introducing serious error.
4. The price at which the gas is to be sold.
5. The cost of drilling the well to the depth at which the sand is expected, the royalty or property charge, and the producing expenses.

Of the groups of data listed above the one that usually is most difficult to obtain is that relating to the decline of wells. Standard curves of the decline of wells are essential to the rational development of any field, and the recording of the data necessary to plot them can not be too strongly urged upon gas operators.

SUMMARY.

The wells in a small pool are closely related to one another, and their productivity and its decline are controlled by fairly definite laws. The figures presented in the foregoing pages are based on statistics of wells in the Cleveland field, where water does not seem to follow up the gas in the sand. Although these figures show many irregularities, they are believed to furnish a sound basis for the following generalizations, which apply most closely to small pools in which water does not follow up the gas:

1. The initial rock pressure of a new well in a small pool is lower that the initial rock pressures of the older wells—that is, the rock pressure of all the wells at any one time is approximately the same, and declines at about the same rate.

2. The rate at which the rock pressure declines is controlled by the rate at which gas is removed from the sand, or in general practice largely by the number of wells per unit area.

3. The initial open flow of a well depends largely on the initial rock pressure, being generally small if the pressure is low; hence the later wells, having lower pressures, usually have smaller flows than the earlier ones.

4. During the life of a well the open flow declines as the rock pressure declines, though not at the same or at a uniform rate.

5. As most wells deliver gas into a pipe line against pressure, the quantity of gas they yield is much smaller than their open flow.

6. The proportion of the open flow delivered into the pipe line depends chiefly on the difference between the rock pressure and the back (line) pressure; hence the production of a well against a constant line pressure normally decreases faster than the rock pressure or the open flow.

7. As most of the wells in a small pool decline at about the same rate, the life of the later wells is generally shorter than the life of the earlier ones.

8. In general the later wells in a small pool have lower initial pressures and smaller flows than the earlier wells; as their pressures are lower, they deliver a smaller percentage of their open flow into the pipe line; as they decline about as rapidly as the older wells, their productive period or life is shorter. In the Cleveland field many of the later wells did not produce enough gas to pay the cost of drilling.

9. As the initial pressure of a well chiefly determines its initial flow, it is possible, from a study of the record of decline in pressure, to estimate in advance of drilling the probable initial flow of a well brought in on a given date. The figure obtained may be evaluated according to the theory of probability and expressed as so many chances in 100. From the probable initial flow of a well an excellent idea can be formed of the value of its total production, and by balancing this figure against the total cost the profit or loss can be roughly ascertained.

10. The rate of decline of pressure is an accurate and convenient index of the stage of exhaustion of a pool and furnishes an excellent basis for determining the point at which new development should cease. In most gas fields wells drilled after the local pressure has declined to one-third of its original amount are probably unprofitable, and in some fields this point may be reached when the pressure has declined only one-half. A general study of the critical stage in the decline of pressure, below which new wells are likely to be unprofitable, would be of great value.

STRUCTURE OF THE NORTHERN PART OF THE BRISTOW QUADRANGLE, CREEK COUNTY, OKLAHOMA, WITH REFERENCE TO PETROLEUM AND NATURAL GAS.

By A. E. Fath.

INTRODUCTION.

The Bristow quadrangle lies in Creek County, in northeastern Oklahoma, between meridians 96° 15′ and 96° 30′ and parallels 35° 45′ and 36°. (See Pls. III and IV.) It is bordered by some of the most prolific oil fields of Oklahoma, yet within its boundaries only a few gas wells have been drilled and a very small quantity of oil has been found. To the west are the Cushing oil and gas field and its southward extension in the vicinity of Shamrock. In fact, the nearest wells of the east Cushing field are only about 1½ miles distant from the Bristow quadrangle. About 9 miles east of the quadrangle is the Glenn oil and gas pool, and in the area that lies between the Bristow quadrangle and the Glenn pool there are several minor fields. Several anticlines and numerous faults were found in the northern part of the quadrangle. A few of the anticlines appear to be sufficiently large to be well worth prospecting with the drill. Several others, which are comparatively small and closely related to faults, are not considered to be worth prospecting until after the larger ones have been developed and prove their value. Although faults alone may cause accumulations of petroleum and natural gas, those in this quadrangle are probably of little value for this purpose. As the information collected in the northern part of the quadrangle is valuable at the present time, it is being published at an early date rather than withheld until the examination of the remainder of the quadrangle is completed.

ACKNOWLEDGMENTS.

The writer is indebted to many individuals and companies for information which has added value to the report. To Mr. R. H. Wood, of this Survey, is due credit for unpublished information concerning the stratigraphy of the Hominy quadrangle, to the north. The well logs at the end of the report were donated by the individuals and companies whose names appear with them. To all who have been of assistance the writer is sincerely grateful.

GEOGRAPHY.

SURFACE FEATURES.

The surface of the quadrangle ranges in altitude between 675 and 1,075 feet above sea level. It is dissected by innumerable streams, and the larger part of its surface is covered with a thick growth of timber, which, on the uplands, consists principally of black and post oaks and is generally so low-branched and thick that it cuts off from view almost everything beyond a distance of a few hundred feet. Small areas of open prairie are scattered here and there, and clearings also help to lay the country open to view.

The area is drained by tributaries of both Arkansas and Canadian rivers. The divide between these streams nearly bisects the quadrangle from east to west. Polecat Creek is the main tributary of the Arkansas in this region, and Little Deep Fork Creek of the Canadian. These two creeks and their larger branches carry some water the year round. Flood plains are well developed in the valleys of all the larger streams, and the valleys of even the smaller branches contain a considerable amount of silt. The timber on the flood plains differs from that on the uplands; it consists principally of elm, sycamore, willow, walnut, and pecan.

ACCESSIBILITY AND DEVELOPMENT.

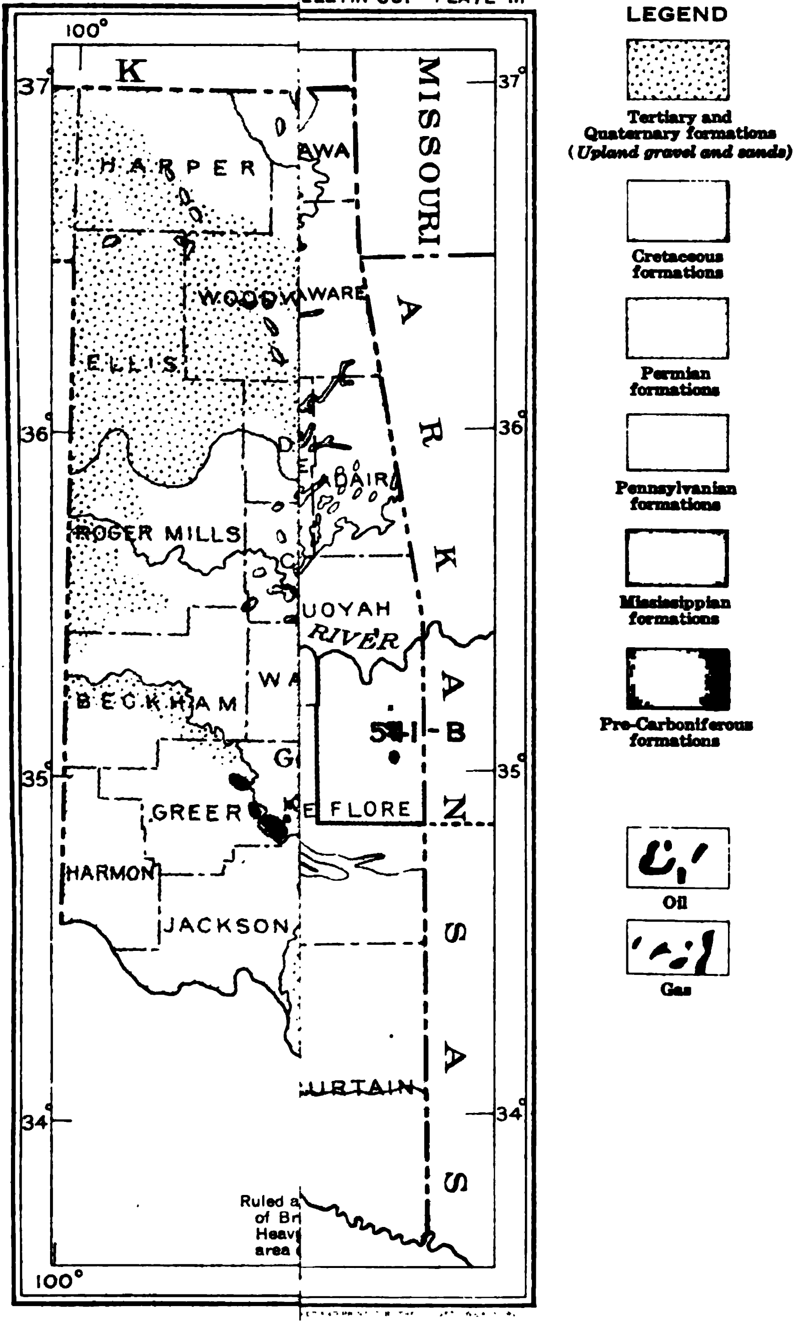
But one railway, the St. Louis-San Francisco (Oklahoma City line), traverses the quadrangle. The only town is Bristow, a thriving business center with a population of about 2,500, situated on the railroad in the south-central part of the quadrangle. Bristow lies 83 miles northeast of Oklahoma City and 36 miles southwest of Tulsa. Heyburn, a small settlement about 8 miles northeast of Bristow, consists of a post office, store, cotton gin, and several houses. Bellvue is a store and post office in the northwestern part of the quadrangle. Just beyond the west border, on the railroad, is the town of Depew.

The roads in general are sandy. Most of them follow the section lines; the others follow the older and more natural routes, such as the divides. They receive but little attention, although an effort is made to keep in repair a few of the more traveled routes for the use of automobiles.

Farming is the principal industry of the region, and cotton, corn, hay, and oats, named in the order of their importance, are the chief crops.

Because of its closeness to the developed oil fields, considerable wildcat drilling has been done in the area described in this report. Up to August, 1916, fourteen wells had been drilled, all of which except one gas well, in sec. 36, T. 17 N., R. 9 E., were abandoned as dry holes.

U. S. GEOLOGICAL SURVEY LLETIN 661 PLATE III



GEOLOGY.

STRATIGRAPHY.

GENERAL FEATURES.

The rocks exposed at the surface in the Bristow quadrangle and those beneath it to a depth of 2,500 feet or more are a part of the Pennsylvanian series, the series to which belong the surface rocks throughout the oil fields of northeastern Oklahoma. Below the Pennsylvanian rocks lie those of the Mississippian series, which in the eastern part of this quadrangle have been penetrated by three wells.

The oil man's interest in the rocks is due to the fact that the surface rocks furnish the means of determining the geologic structure, which is the best governing factor in locating favorable oil and gas territory in advance of drilling, and the deeply buried rocks contain the oil and gas bearing sands.

The classification and most of the names used in the text and columnar sections of this paper are derived from the reports on the Cushing[1] and Glenn pool[2] oil fields, and from unpublished manuscript and maps by R. H. Wood, of this Survey, who has worked in the Hominy quadrangle, to the north.

EXPOSED ROCKS.

KINDS OF ROCK AND CHARACTER OF OUTCROP.

The strata exposed in the northern part of the Bristow quadrangle have an aggregate thickness of about 950 feet. They consist almost entirely of alternating sandstone and shale, the only exceptions being a few limy beds in the eastern part of the area. The limy beds, the Dewey limestone and the calcareous Tiger Creek sandstone (the latter here differentiated for the first time), together with the Elgin sandstone, will be described, and their outcrops are indicated in figure 14. All the other sandstones and shales that were used in working out the geologic structure are so similar to one another in lithologic characteristics that descriptions would be of little value to drillers for differentiating them.

Sandstone and shale each constitute about half of the total thickness of the rocks. (See Pl. IV.) The sandstones appear to form much the greater part, owing to the generally sandy nature of much of the surface, but a close study shows that this does not indicate the true character of the rocks beneath the surface soil. The narrowness of the sandstone and shale belts permits the residual sand of the former to wash and blow as a veneer over the outcrops of the latter, and in consequence the more prolific vegetation which is dependent on a sandy soil grows equally well on the narrow belts underlain by shale. For this reason the black and post oak timber, which ordinarily is limited to sandstone areas and therefore generally helps to differentiate the sandstone from the shale in regions where the belts of the two rocks are broad, covers most of the Bristow region and in this way disguises the presence of shale. The contacts of the shale with the adjoining sandstone beds, upon which practically all the geologic work in the quadrangle depends, are therefore distinguishable only with difficulty, a condition which makes the work extremely tedious and in some localities very uncertain.

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[1] Buttram, Frank, The Cushing oil and gas field, Okla.: Oklahoma Geol. Survey Bull. 18, 1914.

[2] Smith, C. D., Glenn oil and gas pool and vicinity, Okla.: U. S. Geol. Survey Bull. 541, pp. 34-48, 1914.

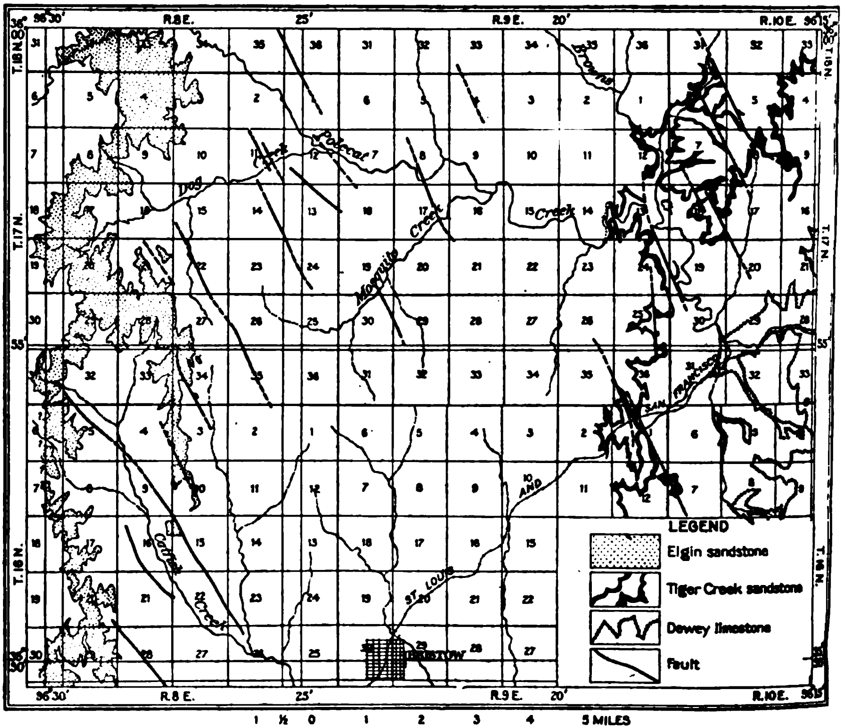
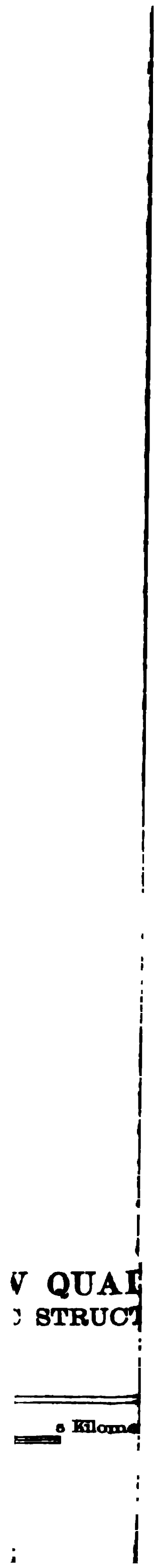


FIGURE 14.—Sketch map showing areal distribution of Elgin sandstone, Tiger Creek sandstone, and Dewey limestone in Bristow quadrangle, Okla.

ELGIN SANDSTONE.

The Elgin sandstone is the highest sandstone bed of considerable thickness in the quadrangle and crops out along or near the western border. (See Pl. V and fig. 14.) It does not differ from most of the other sandstones of the region in lithologic characteristics, but it is described here principally for the benefit of those geologists who may desire to know its position within the quadrangle. It forms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the westernmost thick sandstone in the area described in this report. Where it enters the quadrangle at the north, in secs. 32 and 33, T. 18 N., R. 8 E., its thickness is not determinable, but in the southwest corner of sec. 21, T. 17 N., R. 8 E., a thickness of 50 feet was measured. The base of the sandstone is known to be irregular to the north of this point, and hence it may be assumed that the thickness also varies. To the south of sec. 21, T. 17 N., R. 8 E., the sandstone appears to vary but little for at least 4 miles, but in several places south of secs. 7 and 8, T. 16 N., R. 8 E., its thickness seems to be as much as 80 feet.

The Elgin is overlain by about 150 feet of shale, sandstone, and limestone, which separate it from what is known as the Pawhuska limestone in the Cushing field.[1]

TIGER CREEK SANDSTONE.

The Tiger Creek sandstone, which is differentiated here for the first time, is well exposed in the southern part of sec. 6, T. 17 N., R. 10 E., on the south side of a small tributary to Tiger Creek, from which it receives its name. (See fig. 14.) Its thickness ranges from 20 to 30 feet, and it is low in the stratigraphic section exposed in the Bristow quadrangle. (See Pl. V.) It is the lowest outcropping bed that overlies the shale 100 to 130 feet thick, whose outcrop extends from sec. 4, T. 17 N., R. 10 E., to and beyond sec. 7, T. 16 N., R. 10 E. This position with respect to a thick shale bed not only makes its outcrop more prominent in comparison with other sandstones in the quadrangle, but it has other features that mark its individuality.

Its lower 2 or 3 feet is highly fossiliferous, containing innumerable impressions of the fossil *Fusulina*, which resembles a wheat grain. This probably is its most persistent feature. The *Fusulina*-bearing portion is observable only where the surface conditions are favorable for its exposure, in such places as a roadway cut or a creek bank. The sandstone, as a whole, varies greatly in lithologic character. In some places it is a light-gray to yellowish-brown friable sandstone that can not be distinguished from other sandstones in the region, but in other places as much as one-half or more of it is so calcareous that it can truthfully be called a limestone. In still other places the *Fusulina*-bearing portion is separated from the upper portion by as much as 15 feet of shale. All gradations between these various phases are known—from limestone through sandy limestone and limy sandstone to common siliceous sandstone—and any or all of these phases may be present as layers or lenses in a single exposure. The limestone phase is more highly developed in the northern part of the quadrangle, where it generally forms the top part of the Tiger Creek sandstone, and in this locality it carries fossils, principally segments of crinoid stems and *Fusulina*. The limestone phase is gray on a fresh surface but weathers to reddish brown by the oxidation of its iron content.

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[1] Buttram, Frank, The Cushing oil and gas field, Okla.: Oklahoma Geol. Survey Bull. 18, p. 8, 1914.

In the Hominy quadrangle,[1] to the north, this bed lies above the Avant limestone. At Arkansas River the distance between the two beds is 60 feet. South of Arkansas River both the Avant limestone and the shale that separates the Avant from the Tiger Creek sandstone decrease in thickness, and near the southern boundary of the Hominy quadrangle the Avant limestone is only a foot or two thick and the Tiger Creek sandstone is separated from it by only 3 to 5 feet of shale. The Avant probably thins out and disappears before reaching the Bristow quadrangle. As the base of the Tiger Creek sandstone lies so close to the Avant, only a short distance to the north, it may be assumed to be practically the equivalent of the horizon of the Avant in the Bristow quadrangle. Because the Tiger Creek sandstone is a bed of somewhat unusual character and persistency, it is used as the key bed to which the contours of Plate IV refer.

DEWEY LIMESTONE.

In the Bristow quadrangle the Dewey limestone lies between 160 and 220 feet below the Tiger Creek sandstone. (See Pl. V.) At no place in the quadrangle where it was observed did it measure over 1½ feet, and at several places it measured less than 9 inches in thickness. It is light gray on a fresh surface but weathers yellowish brown to reddish brown, owing to the oxidation of its iron content. It carries abundant fossils of both *Fusulina* and segments of crinoid stems. Because of its thinness its exposures are limited to particularly favorable places, such as stream banks. Its largest exposure is at the ford on Polecat Creek in the SE. ¼ sec. 30, T. 17 N., R. 10 E. (See fig. 14.) Other scattered exposures may be found in secs. 21, 29, and 33, T. 17 N., R. 10 E., and secs. 5, 6, and 8, T. 16 N., R. 10 E. Care must be taken not to confuse the Dewey limestone with a very lenticular limy sandstone (in some places sandy limestone) which lies about 20 feet below it in secs. 21, 28, 29, and 33, T. 17 N., R. 10 E., and which, because of its lenticularity, is not considered to be worthy of a description in this report.

ROCKS NOT EXPOSED.

GENERAL CONSIDERATIONS.

The unexposed rocks of the Bristow quadrangle are of interest in this discussion principally because they contain the oil and gas bearing sands. The most direct method of obtaining information concerning oil and gas sands is from well records, but as the wells in that part of the quadrangle here described are widely scattered, and

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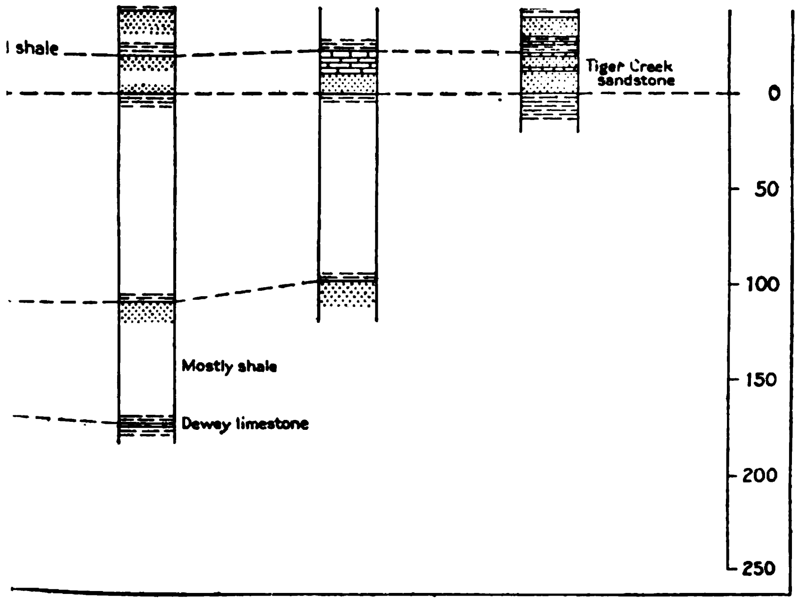
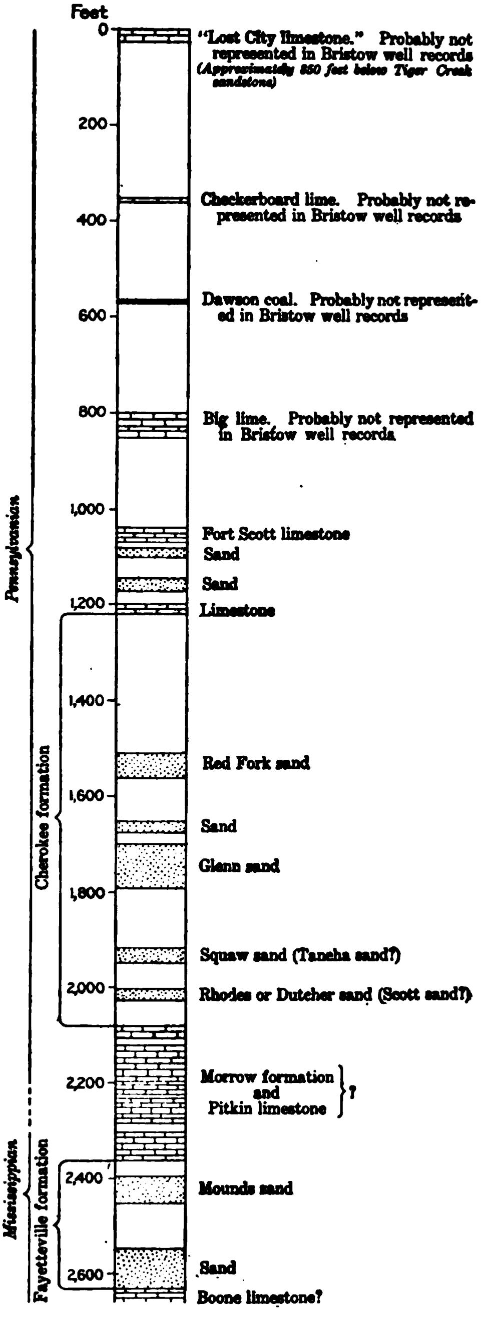
[1] Personal communication from R. H. Wood.


shale
Tiger Creek sandstone
Mostly shale
Dewey limestone

RANGLE, OKLA.

the logs of the drilling are not complete, and for most of the wells not given in detail, information from this source is meager. Moreover, the little information available is rather unsatisfactory because of the nonpersistency of key rocks from well to well, so that it is impossible to determine definitely the nature of the changes that take place in the individual beds.


Feet
0
200
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1,000
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1,400
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2,600
"Lost City limestone." Probably not represented in Bristow well records *(Approximately 850 feet below Tiger Creek sandstone)*
Checkerboard lime. Probably not represented in Bristow well records
Dawson coal. Probably not represented in Bristow well records
Big lime. Probably not represented in Bristow well records
Fort Scott limestone
Sand
Sand
Limestone
Red Fork sand
Sand
Glenn sand
Squaw sand (Taneha sand?)
Rhodes or Dutcher sand (Scott sand?)
Morrow formation and Pitkin limestone ?
Mounds sand
Sand
Boone limestone?
Pennsylvanian
Cherokee formation
Mississippian
Fayetteville formation

FIGURE 15.—Composite skeleton stratigraphic section of the Glenn pool region, Oklahoma.

In the adjoining oil fields, where there are many drill holes, the character of the underground strata is fairly well known. By tracing these beds from well to well toward and into the Bristow quadrangle some suggestions as to the character of the extensions of the beds within the quadrangle may be obtained. This was done by studying numerous well records from the Cushing field, the Glenn pool, and the area separating the Glenn pool from the Bristow quadrangle.

LIMESTONES AND OIL AND GAS SANDS OF THE GLENN POOL REGION.

In northeastern Oklahoma the best key rocks, both among those which crop out at the surface and among those encountered in drilling, are limestones. In the Glenn pool region (see fig. 15) the Fort Scott ("Oswego") limestone, a limestone about 150 feet below the Fort Scott, the limestones of the Morrow formation, and the Pitkin limestone are the beds that can be of possible service in correlating from well to well toward the Bristow quadrangle.

The Fort Scott ("Oswego") limestone and the limestone about 150 feet below it are, according to Smith,[1] well-defined beds penetrated by all the wells in the Glenn pool. West and southwest of the Glenn pool, however, the recognition of both or either of these beds in well records is difficult. In the northeastern part of the Bristow quadrangle their identification seems positive, and there is some evidence for believing that the Fort Scott ("Oswego") extends across the northern part of the quadrangle. The limestone 150 feet below the Fort Scott, on the other hand, appears to thin out or else is represented only by a "limy shell" (thin limestone parting in the shale). Toward the south both of these beds are probably absent or are represented only by thin "lime shells."

The Morrow and Pitkin limestones of the Glenn pool are penetrated by three wells in the Bristow quadrangle—in sec. 1, T. 16 N., R. 9 E. (see log, p. 97), sec. 6, T. 16 N., R. 10 E. (see log, p. 98), and sec. 32, T. 17 N., R. 10 E. (see log, p. 99). West of these localities no wells are deep enough to reach these beds. The three wells mentioned have not penetrated below the Pitkin limestone, and hence there is no evidence as to the presence or absence of the Boone limestone ("Mississippi lime").

The productive oil and gas sands of this general region have considerable stratigraphic range. The Cherokee formation, which lies above the Morrow formation and below the Fort Scott ("Oswego") limestone, contains in descending order the Red Fork, Glenn, Taneha, and Scott sands of the Glenn pool region (the Scott is considered by many oil men to be the equivalent of the Rhodes and Dutcher sands), and the Bartlesville and Tucker sands of the Cushing field. The Layton and probably the Wheeler sands of the Cushing field lie above the Cherokee shale. So far as well records show, all these sands are more or less lenticular, varying in thickness from place to place and dividing or even thinning out completely. In some places they are distinct beds and are separated from one another by shale beds of nearly uniform thickness. In other places, however, the oil sands are less distinct and are interbedded with other sands that are not known to bear either oil or gas. Conditions such as these make it difficult and in places impossible to correlate the sands from one well to another unless the wells are close together. The inaccuracy of many well logs greatly increases this difficulty.

The Red Fork sand of the Glenn pool region extends westward into the Bristow quadrangle. It is found at a depth of 2,115 feet in the well in sec. 32, at 2,100 feet in the well in sec. 20, and at 2,055 feet in the well in sec. 30, T. 17 N., R. 10 E.; at 2,275 feet in a well in sec. 6, T. 16 N., R. 10 E.; and at 2,344 feet in sec. 1, T. 16 N., R. 9 E. In the logs of all these wells the sand is reported to contain oil and gas but not in paying quantities. West and southwest of these wells there is much uncertainty in correlation, and the extent of the Red Fork sand in this direction is not known.

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[1] Smith, C. D., The Glenn oil and gas pool and vicinity, Okla.: U. S. Geol. Survey Bull. 541, p. 20 and cross sections of pl. 3, 1914.

The Glenn sand, so far as well records show, is comparatively thick in the northeastern part of the Bristow quadrangle, but to the west it thins rapidly. It is possibly the producing sand at a depth of about 2,500 feet in a few oil and gas wells several miles south of the town of Bristow.

The Taneha sand, which lies 100 or more feet below the Glenn, is probably very thin or else absent in the Bristow quadrangle.

The Scott (Rhodes and Dutcher) sand, which lies a short distance below the Taneha, is the producing sand in the Scott pool, south of Kellyville, a few miles east of the Bristow quadrangle. It is probably a lenticular bed and absent in most of the wells in the quadrangle, although they have penetrated its horizon about 100 feet above the Morrow formation.

The Mounds sand, which is the producing sand south of the Glenn pool, near the town of Mounds, lies in the Fayetteville formation, below the Pitkin limestone. As no wells in the Bristow quadrangle have passed through this limestone, there is no evidence regarding the presence or absence of the sand within the quadrangle.

OIL AND GAS SANDS OF THE CUSHING FIELD.

The Layton sand of the Cushing field extends into the Bristow quadrangle, but it does not appear to be a well-defined bed that can always be recognized by the drillers. Failure to recognize this sand may, however, be due to the fact that it carries no oil where penetrated in the Bristow quadrangle.

The Wheeler sand of the Cushing field, according to Buttram,[1] is a porous limestone that has been considered to be the Fort Scott limestone ("Oswego lime") or its equivalent. As the Fort Scott limestone is believed to be present in some places in the northern part of the Bristow quadrangle, the Wheeler sand, its probable equivalent, should also be considered as present.

The Bartlesville sand, which is the most productive sand in the Cushing field, appears to thin considerably to the east, where it enters the Bristow quadrangle. This thinning and the fact that it is not parallel[2] to the surface rocks in the Cushing field make the recognition of the Bartlesville sand in the wells of the Bristow region somewhat uncertain. From the meager information to which the writer has access this lack of parallelism seems to be most pronounced below the Layton sand. Owing to the thinning of the Bartlesville toward the east, it can not be differentiated by its thickness from several other sands that are recorded at about the same position in the well logs of the Bristow quadrangle, and hence there is no means by which it may be certainly recognized in this region.

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[1] Buttram, Frank, The Cushing oil and gas field, Okla.: Oklahoma Geol. Survey Bull. 18, p. 41, 1914.

[2] Idem. This is clearly brought out by comparing Buttram's plates 1 and 11.

The opinion is prevalent among many oil men that the Bartlesville sand of the Cushing field is the same as the Glenn sand of the Glenn pool. This opinion no doubt is due to the fact that these sands were among the most productive in their respective fields. If they are the same it should be expected that the area between the Cushing field and the Glenn pool, principally the northern part of the Bristow quadrangle, would furnish the proof. But as indicated above, the thinning of the Glenn sand to the west and of the Bartlesville to the east and the lack of parallelism between the Bartlesville and the overlying beds furnish little evidence in support of this contention.

The Tucker sand of the Cushing field does not appear to be a regular and well-defined bed, and the name seems to be more or less loosely applied. Where an oil-bearing sand is found beneath the Bartlesville, it is called the Tucker without much regard as to the distance between them.

STRUCTURE.

DEFINITION.

To many the term "structure" as used in oil reports has a vague meaning and is frequently misunderstood. It pertains to the position or lay of the rock beds and not to their composition or to the material which they may contain. Stratified rocks, like those of the Bristow quadrangle, lie in layers, one upon another in a manner somewhat similar to the leaves of a book. The rock layers, however, are not of uniform thickness, like the leaves of a book; they thicken and thin and may even pinch out. Rock layers that lie horizontal, like the leaves of a flat-lying book, are said to have flat, level, or horizontal structure. The surface of the earth above such flat-lying rocks, on the other hand, may be very far from flat or horizontal, being cut up into hills and valleys.

Few of the rock layers of the earth, however, lie flat; most of them are inclined or tilted, folded, broken, or upturned (vertical), and the structure of such layers is said to be inclined (dipping or monoclinal), folded (anticlinal, domal, or synclinal), faulted, or vertical, as the case may be. The same rocks may be horizontal in one locality and inclined, folded, or faulted in another. An upfold or arch of the beds is an anticline and a downfold or trough is a syncline. These features also as a rule do not correspond with the surface features, for anticlines (upfolds) may occur beneath valleys in the hills and ridges, or on the slopes between hills and valleys, or they may even cross from the highlands into the lowlands. Synclines (downfolds) in like manner may occur beneath either hills or valleys or may extend across both hills and valleys.

By structure, then, is meant the general position in which the rock layers lie. Petroleum geologists often use the term in a slightly different sense; they speak of a "structure" in some particular locality when in reality they mean a structural feature of a particular kind, as an anticline or dome or a feature of some other type that is favorable for the accumulation of oil and gas. The term should preferably be confined to its general meaning—that is, it should be used as an abstract term, like stratigraphy or topography, and of course in that sense the plural "structures" would be as inadmissible as "stratigraphies."

REGIONAL STRUCTURE.

Considered in a broad way, the rock beds of northeastern Oklahoma dip or descend westward at a very low angle. In the Bristow quadrangle the dip is slightly north of west and amounts to about 50 feet to the mile, or a little more than half a degree. As the surface of the quadrangle slopes slightly eastward—that is, in a direction opposite to the dip of the rocks—the rock beds where they come to the surface are beveled at a very low angle and their outcrops extend in belts running in a general way from south to north. The rocks that are stratigraphically the lowest, therefore, crop out at the east side of the quadrangle, and each succeeding belt of outcrops from east to west represents in general beds younger and higher in the stratigraphic section. However, the westward slope of the rock beds is not uniform; it is modified by variations in the rate of dip, local folds, and small faults, all of which are represented on Plate IV by structure contours. As the dip is generally westward, dips to the east are uncommon and are locally referred to as reverse dips. Accumulations of oil and gas are generally found in close relation to local irregularities in the general structure of a region, and it is to such folds and irregularities that attention will be principally directed in this paper.

FIELD METHODS OF DETERMINING STRUCTURE.

The topographic map of the Bristow quadrangle made by the United States Geological Survey in 1914 and 1915, in cooperation with the Oklahoma Geological Survey, was used as the base on which all the geologic observations were plotted. The structure was determined by locating on the map and determining the altitude of the outcrops of numerous specific rock layers, among which are the Elgin and Tiger Creek sandstones and the Dewey limestone, described on preceding pages. Almost all the contacts of shale and sandstone that may be seen in this region and could be traced for even a mile or two were used in determining the structure. Because the several contacts of sandstone and shale can not be differentiated from one another lithologically, it was necessary, in order not to confuse one with another, to traverse the entire outcrop of every such contact traced. Although this was an extremely slow and tedious method, it was the only one that was at all reliable, and even it is not considered infallible for this region. Local stratigraphic sections were measured wherever several successive beds were exposed, and these were helpful as a check to the tracing of the various beds.

The accuracy of determinations of altitude demanded by the present-day standards of geologic work requires the use of a spirit level or refined vertical-angle determinations. The latter method was prohibited by the thick timber of the country, and although spirit-level determinations could have been made the denseness of the timber would have made it impossible to take sights averaging more than 200 or 300 feet in length, and for that reason this method was considered too slow and altogether impracticable. In determining the altitude of the beds the aneroid barometer was the principal instrument used. Many of the altitudes so determined were checked by hand leveling, which was done wherever practicable. To indicate the great care used in the determinations it seems advisable to describe the method in detail. The barometer is set at some point whose exact altitude is given on the topographic map or indicated on the ground by a bench mark, and the time of setting the barometer is noted. The rock outcrops whose altitudes are to be determined are then visited, and the altitudes as given by the aneroid barometer, together with the time of each reading, are recorded. As soon thereafter as possible the barometer is checked on the original or some other accurately determined point. If the reading of the barometer shows any discrepancy from the true altitude at this point, discrepancies probably also exist in the altitudes as read on the outcrops. The readings are then adjusted according to the time which has elapsed between the original setting of the barometer and each reading. The time that elapsed between the setting and checking of the barometer in such traverses ranged between half an hour and two hours. If the atmospheric pressure has been constant or has been changing at a uniform rate, the altitudes thus determined may be considered as approximately correct. If at some subsequent time an outcrop is again visited, a second reading is taken to check the original. Should such a check reading not accord with the original determined altitude within a few feet, or should the geologist have any reason for suspecting any appreciable error in the determination, the work is done over until there is a reasonable check and the determinations can be considered approximately correct. Many determinations of altitude have been checked within a few feet as many as three or four times. Such checking and rechecking leaves but little chance for errors of any appreciable size. The checking has been particularly careful in the areas of the anticlines and faults.

METHOD OF REPRESENTING STRUCTURE.

The most practicable method of representing geologic structure on a map is by means of structure contours. A structure contour is a line connecting all points on the key bed to which it refers that have the same altitude. For instance, the 400-foot contour on Plate IV shows the line along which the base of the Tiger Creek sandstone is 400 feet above sea level, and in like manner the 410-foot contour indicates an altitude of 410 feet, and the 390-foot contour an altitude of 390 feet. The "contour interval" (the vertical distance between the altitudes represented by adjacent contours) used on Plate IV is 10 feet. It is possible to determine from the spacing of the contours the shape or lay of the key rock to which they refer. Where the contours are close together, the dip is greater than where they are widely separated.

Inasmuch as the Tiger Creek sandstone crops out over a relatively small part of the region its altitude in localities west of its area of exposure must be computed by adding or subtracting, as the case may be, its distance below or above the other outcropping geologic contacts which were traced and whose altitude was determined. In thus computing the altitude of the base of the Tiger Creek sandstone over the region it must necessarily be assumed, in the absence of evidence to the contrary, that the intervals between the base of the sandstone and each succeeding bed are the same underground as at the surface, where they can be determined. However, it is almost certain that these intervals are not constant. Well logs, if they recorded the Tiger Creek sandstone, would be a great help in determining the accuracy of the computed altitudes on this bed, but it can be recognized with some uncertainty in only one of the records (see log on p. 97) of the eight wells which penetrate its horizon in the northern part of the Bristow quadrangle.

As already described most of the sandstones and shales vary in thickness from place to place along their outcrops. This is well illustrated by Plate V. If the thicknesses of individual beds are not constant at the surface it is presumable that they are also not constant beneath the surface, and hence that the distances between the several beds and the Tiger Creek sandstone may be variable from place to place. Nevertheless, it is believed that as a whole the strata in this region obey the general law of sedimentary deposits, the local irregularities compensating one another, in effect, so that the beds in the aggregate are parallel except in so far as a regional separation or convergence in some direction is caused by thickening or thinning of some member or group in that direction. However, on account of this variability of individual beds in their areas of exposure, and because it is not possible to check the elevation of the base of the Tiger Creek sandstone by well records, the computed structure as shown by Plate IV must be considered as only approximately correct.

CATFISH ANTICLINES.

SOUTH CATFISH ANTICLINE.

In the west-central part of the Bristow quadrangle, extending from secs. 28 and 29, T. 17 N., R. 8 E., southward to secs. 33 and 34, T. 16 N., R. 8 E., is an area where there is considerable folding and extensive faulting. In this area a short anticline, here called the South Catfish anticline, extends from the NW. ¼ sec. 16 to the NW. ¼ sec. 9, T. 16 N., R. 8 E. The reverse (eastward) dips that mark one side of this fold are seen in the rocks that lie between the valley of Catfish Creek and the fault that crosses secs. 9 and 15. The eastward descent of the beds, which ranges from 10 to 90 feet or more, according to location along the fold, can be determined only by obtaining the altitudes of the same beds on the opposite side of the valley. The beds were correlated by tracing those on the east side northward and across the valley and then southward on the west side of the valley. The fault in secs. 9 and 15, the downthrow of which is on the west side, is probably the cause of most of the easterly dip in the southern part of sec. 9 and the northern part of sec. 16. As the westward dip on the west side of the anticline was observed as far east as the west side of secs. 9 and 16, the crest is located somewhat farther east in a place where there are few if any rock outcrops. Because of the lack of outcrops the details of configuration of the anticlinal crest can not be determined.

The southward extension of the anticline into sec. 16 is interrupted by another fault with a northwesterly trend. The east flank of the anticline continues without interruption for some distance along the northeast side of this fault, as shown by the dip of the rocks lying between this fault and Catfish Creek, in the S. ½ sec. 16. The north end of the anticline plunges gently.

The possibilities of finding oil and gas in this anticline are discussed on pages 89–90.

NORTH CATFISH ANTICLINE.

North of the South Catfish anticline is another fold, the North Catfish anticline, which is terminated on the south by the fault that crosses sec. 5, T. 16 N., R. 8 E. This fold is not symmetrical but pitches northward until it merges into the regional westward dip in secs. 28 and 29, T. 17 N., R. 8 E. The eastward dip on this anticline is slight in sec. 28 and the northern part of secs. 32 and 33, but in the southern part of sec. 32 the upfolding of the upthrown block of the fault to the south is noticeable, and in the northeastern part of sec. 5 and the northwestern part of sec. 4 the maximum eastward

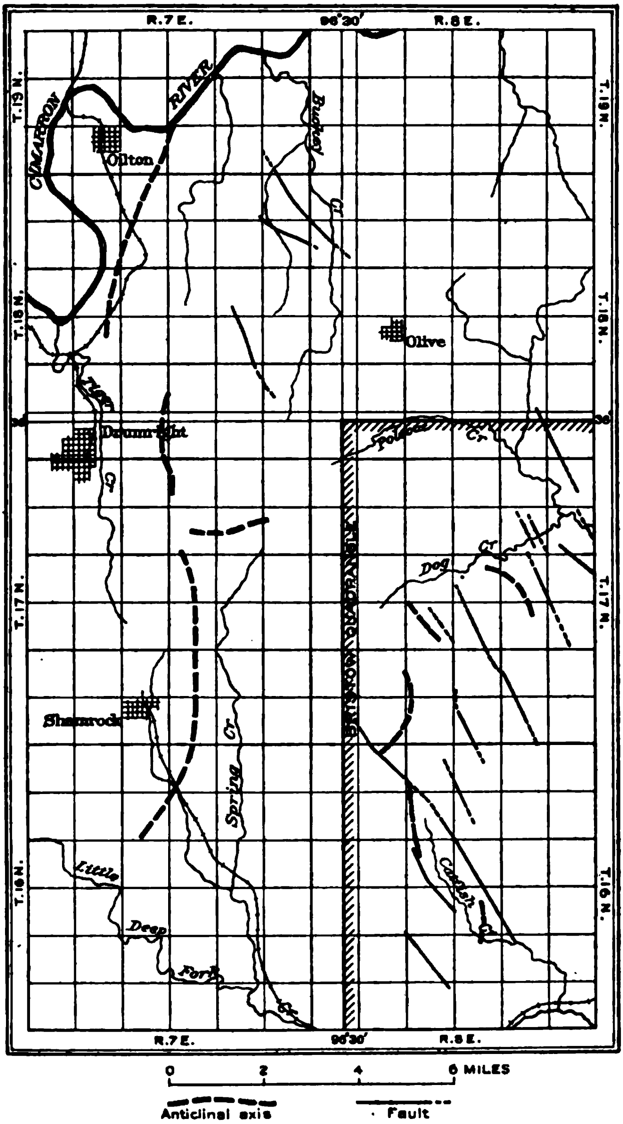

FIGURE 16.—Sketch map showing location of axes of Catfish anticlines and the anticlines of the Cushing oil and gas field, Oklahoma.

dip is reached. This reverse dip extends eastward to the syncline in sec. 4, T. 16 N., R. 8 E., and sec. 33, T. 17 N., R. 8 E.

The possibilities of finding oil and gas in this anticline are discussed on page 90.

RELATION TO CUSHING ANTICLINES.

The combined extent of the North and South Catfish anticlines is about 4 miles, and, if taken together, they are comparable in size to some of the Cushing anticlines. They lie but 6 miles east of the Shamrock dome and its probable extension south of the area mapped by Buttram [1] in the Cushing field and have approximately the same trend. (See fig. 16.)

Because of this close proximity and similar trend, and because the combined extent of the two anticlines is similar to that of some of the Cushing anticlines, it seems reasonable to suppose that the Catfish anticlines were formed at the same time and under the same conditions as the Cushing group of anticlines.

MINOR ANTICLINES.

Scattered over the remainder of the area considered in this report are a few small anticlines that appear to be the result of downfolds in the otherwise northwestward-sloping beds, formed by local folding that accompanied drop faulting, especially where the down-dropped block is on the southwest side. Such an anticline is mapped in sec. 18, T. 17 N., R. 10 E. The folding was caused by the same fault movement that produced the larger or eastern fault. There is little doubt as to the fold in the northwest quarter of this section, but as it enters the valley in the southwest quarter the structure as portrayed on Plate IV may be questioned. The structure in this quarter section is represented as an extension of that to the northeast, but this may not be the true condition, for it is possible that a fault exists in this valley, and, if so, the fold in the northwest quarter must be abruptly terminated.

Other small anticlines, which appear to be due to similar folding that accompanied fault movements, are present in the NW. ¼ sec. 21, T. 17 N., R. 8 E.; sec. 14, T. 17 N., R. 8 E.; sec. 30, T. 17 N., R. 9 E.; the southwestern part of sec. 1 and the northern part of sec. 12, T. 16 N., R. 9 E.; and sec. 22, T. 16 N., R. 8 E. Folds of a similar nature are mapped in secs. 11 and 12, T. 17 N., R. 8 E., but as the field evidence in these localities is not conclusive the folds are shown on the map by dashed contours.

The possibilities of finding oil and gas in these minor anticlines are discussed on pages 90–92.

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[1] Buttram, Frank, op. cit., pl. 1.

FAULTS.

The faults of the Bristow quadrangle are in general parallel and trend approximately N. 30° W. They are all of minor magnitude, both in vertical displacement and areal extent; the largest stratigraphic throw is about 130 feet and the greatest length is about 3½ miles. The faults are roughly grouped in belts that cross the country approximately parallel to the strike of the rock beds.

In this region, where the rock outcrops are so poor and unsatisfactory for determining the details of the geologic structure, it may be well to describe briefly the criteria upon which the mapping of the faults is based. The best evidence, which at the same time is the most unusual, consists in slickensided faces of sandstone outcrops. Plate VI shows the most prominent of such slickensided fault planes observed in the region. At most places such exposures are very small and stand but a foot or two above the surface. An intermittent row of such outcrops marks the course of a fault with certainty. As mentioned above, however, such exposures are exceptional. Moreover, they are limited to places where sandstone and shale are on opposite sides of the fault plane and the shale has been eroded, the sandstone being left standing above the adjacent surface.

The fault movements sheared the rocks adjacent to the fault planes in a zone several feet thick. The fractures in these shear zones have subsequently been filled by veinlets of siliceous or calcareous material, and these veined shear zones are to be seen at many places where the slickensided fault planes are not exposed. Moreover, they are exposed where the opposite sides of the fault consist of sandstone.

Another method of detecting faults is by the discordance of beds on the two sides of the fault, an unsatisfactory method where there are no good horizon markers, as in areas where shale is the surface rock. Still another method, the discrepancy in the position of contour lines as determined from the evidence in hand, was employed in locating a supposed fault in an area of no outcrops in sec. 12, T. 17 N., R. 8 E.

The slickensided surfaces developed in sandstone represent the positions of the fault planes. The plane of the fault in the north-central part of sec. 5, T. 16 N., R. 8 E., is thus indicated as dipping 60° SW. As the dropped block is in the direction of the dip of the fault plane, the fault is of the normal type. The same is true of the fault in the NE. ¼ SW. ¼ sec. 15, T. 16 N., R. 8 E., which dips 55° SW.

There is no direct evidence that thrusting has taken place along any of the faults, nor do any of the structural features suggest thrust faulting, and hence, without evidence to the contrary, all the faults will be considered normal. The dip of the fault planes probably varies. At some places it is probably greater than 60° and at other places less than 55°, which are the measured dips at the localities mentioned above. It is probable that the individual fault planes change in dip from place to place. Those faults whose traces are not altogether straight but are more or less curved or bowed as shown on Plate IV may have these irregular courses because of variation in dip.

A feature of several of the faults, the significance of which has not been determined, is the relation of the buckling of the strata on the upthrown and downthrown sides. As illustrated in figure 17, the beds on the upthrown side are sharply upturned near one end of the fault and those of the downthrown side are sharply downfolded near the other end. This relation is indicated on the structure contour map (Pl. IV) by the bunching of the contours on opposite sides of the faults near the opposite ends of the displacements. Most of the faults represented on Plate IV show this feature.

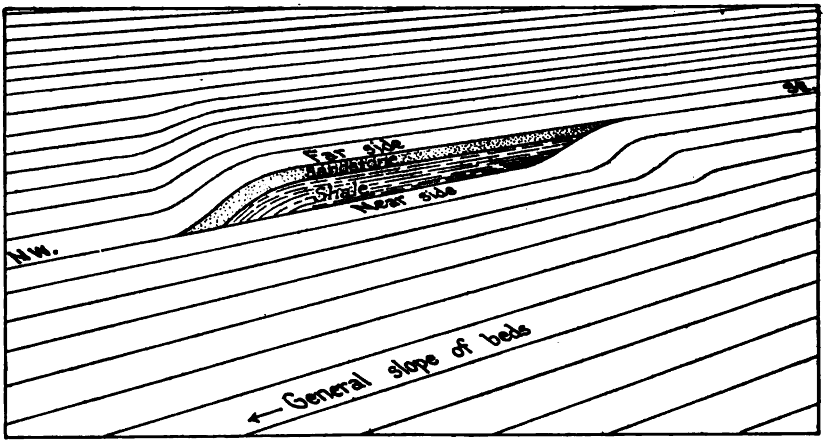
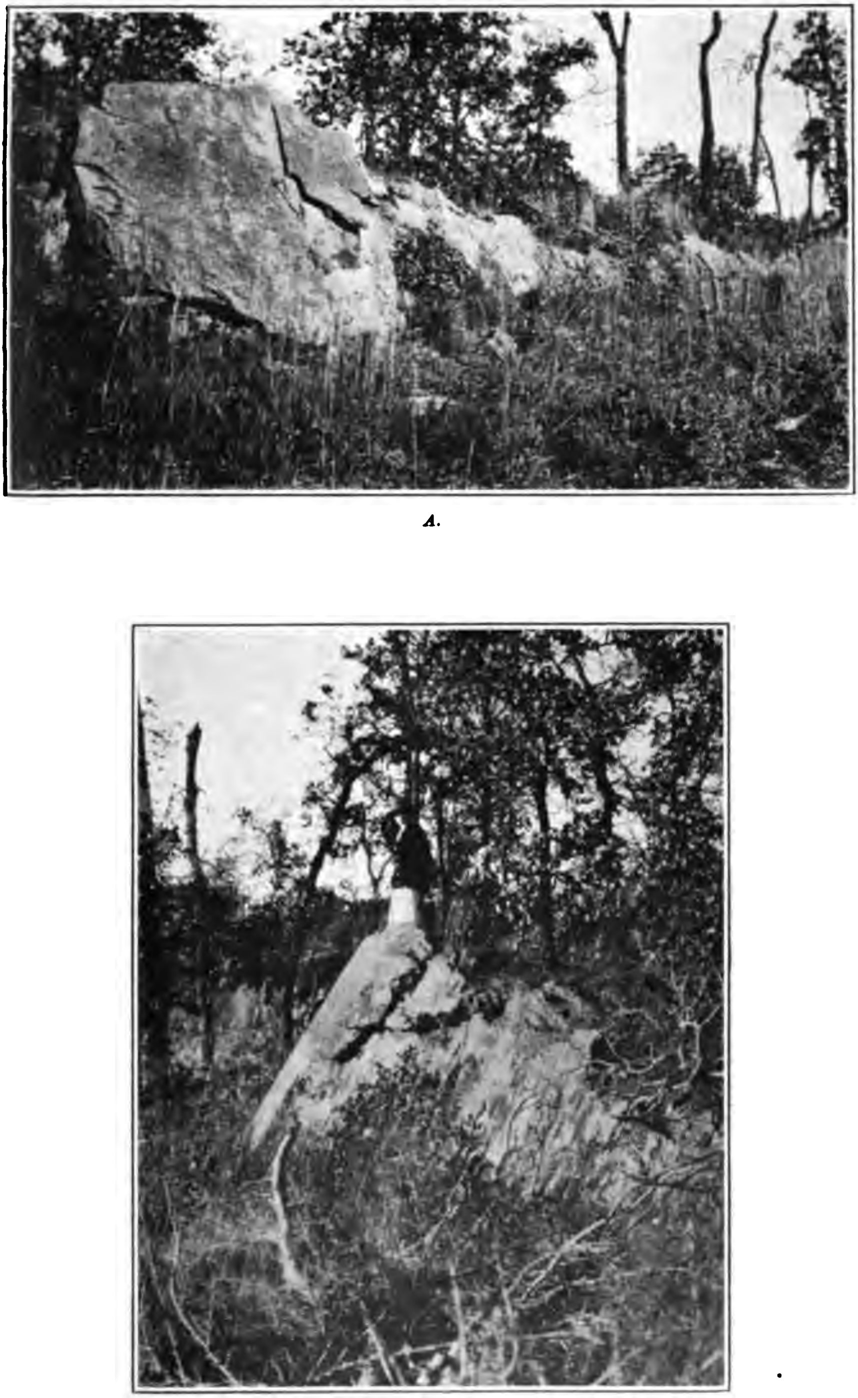


FIGURE 17.—Sketch of a faulted sandstone bed showing the upthrown block (far side) sharply turned down at the northwest end of the fault and the downthrown block (near side) sharply turned up at the southeast end of the fault.

The contouring of the structure in the northern and eastern parts of sec. 3, T. 17 N., R. 8 E., is subject to doubt. There is some evidence of a fault here, but no faults are represented on the map. Because of the doubt as to the real structure in this place, the contouring of the valley region to the north, in secs. 34 and 35, T. 18 N., R. 8 E., must also be considered doubtful.

The oil and gas possibilities of the faults are considered on pages 88 and 92.



A.

B.

FAULT SCARP SHOWING SLICKENSIDED SURFACE OF SANDSTONE PRODUCED BY FAULT MOVEMENT.

RELIABILITY OF THE REPRESENTATION OF STRUCTURE IN THE ABSENCE OF ACCURATE WELL RECORDS.

The representation of the structure on Plate IV is dependent on the visible evidence as to the structure of the surface rocks. In many places the information thus obtained is meager and not absolutely reliable. Nevertheless, the results here given represent much painstaking work, the relative reliability of which in different parts of the region is shown by solid and dashed contours.

As the contouring of the structure of the Tiger Creek sandstone over a large part of the region is based on the structure of its overlying and underlying strata, which form the surface rocks, the actual configuration of this sandstone may vary considerably from the configuration as represented on the map. However, no other method of determining the structure is possible until numerous accurate well records are available to furnish more reliable information, which can be used as a check on the calculated intervals between the strata used in this provisional mapping.

The importance of accurate well records for determinations of structure can not be overstated. They give the most reliable and in many places the only clue as to the actual conditions beneath the surface. The value of reliable knowledge concerning the underground strata for the systematic development of any property is being more fully recognized by many of the oil and gas producers, but as yet there has been no corresponding or really satisfactory advance in the reliability of the logs kept by many of the drillers.

Limestones and producing sands are the best key rocks to be recorded in well logs, and their depth and thicknesses should be determined by steel-line measurements. A statement in a well record of every such steel-line measurement insures greater usefulness for the data and far greater confidence therein on the part of the engineer and geologist. Steel-line measurements should not be limited to limestones and producing sands; they should be made to other beds also, to check the measurements made by the drilling cable. The habit of estimating depths and thicknesses of strata by drillers, however proficient they may be, should be unqualifiedly condemned, as should also their identification of the strata they are drilling by the feel of the cable or the rate at which the drill is progressing. By this method hard sand is very often recorded as limestone and soft sand as shale. Many other discrepancies also appear that could be eliminated by an examination of the drill cuttings. The great discrepancies so frequently to be noted in logs of neighboring wells, which should in fact be very similar, shows how prevalent this habit is and how little value is placed by the driller on data that may be of the greatest importance to the operator in determining the structure and selecting sites for subsequent drilling.

PROSPECTIVE OIL AND GAS AREAS.

GEOLOGIC FEATURES GOVERNING THE OCCURRENCE OF OIL AND GAS.

The geologic features that affect the accumulation of oil and gas may be divided into two general classes—those which can be determined at the surface and those which are due to local conditions beneath the surface. Those features which can be determined at the surface are structural in nature and consist of rock folds (anticlines, domes, etc.) and faults.

Accumulations of oil and gas in rock folds are generally situated at the crests, and the crests are therefore the more favorable localities for testing folds. Faults, on the other hand, may or may not affect the accumulation of oil and gas by sealing the oil and gas bearing sands which they break. Where a fault cuts a rising oil and gas bearing sand, the fault may seal the sand in such a way that the oil and gas are arrested in their upward journey and caused to accumulate. The lower sand at *A* in figure 18 illustrates such a case. A shale bed brought opposite the broken end of a sand bed is probably the most effective method of sealing it. This, however, is not the necessary result of any fault which cuts an oil and gas bearing sand, for another sand may be brought opposite the first sand, as is shown at *B* in figure 18, or the fault plane may be more or less open, so that the sealing in of the oil and gas is not effected. It may be that a sand is sealed over part of the length of a fault and not over the rest. Search for the sealed portions is therefore a very blind process. Obviously the conditions caused by a fault where it cuts an oil and gas bearing sand can not always be determined by an examination of the rocks at the surface.

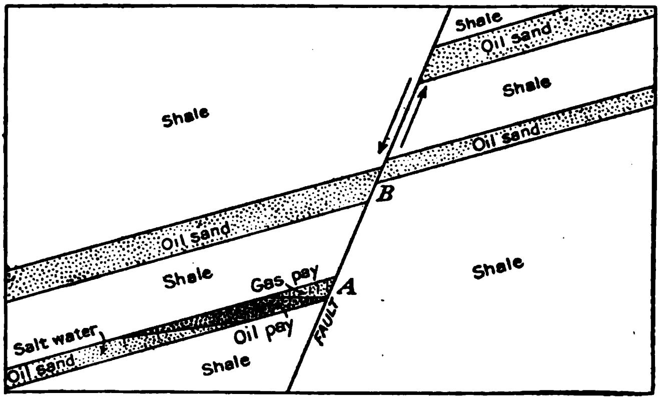


FIGURE 18.—Diagrammatic cross section showing (at *A*) an accumulation of oil and gas caused by a fault and (at *B*) a possible condition under which a fault may not cause oil and gas to accumulate.

Of those local underground geologic features which affect accumulations of oil and gas and which can not be detected by a study of the surface rocks, important examples are sandstones whose upper surfaces are convex, owing to their lenticular shape or to an unconformable relation with the overlying beds; sandstones in which some parts have a higher porosity than other parts; and underground anticlines, domes, and monoclinal folds that do not appear in the rocks at the surface because of unconformities or irregularities in the rocks between.

LOCALITIES OF FAVORABLE STRUCTURE.

GENERAL CONDITIONS.

Surface indications of oil and gas, such as oil or gas seeps or asphalt deposits, were not observed in the Bristow region. However, from the fact that some gas and good showings of oil have been found in the wells that have been drilled, and from the further fact that large quantities of oil and gas have been developed in the Cushing field, immediately to the west, where favorable geologic structure appears to be the controlling influence, it is believed that areas of similar favorable structure are likely to contain paying quantities of oil and gas in the Bristow quadrangle.

SOUTH CATFISH ANTICLINE.

The crest of the South Catfish anticline lies in the western part of sec. 9 and the northwestern part of sec. 16, T. 16 N., R. 8 E. The uncertainty as to the configuration of this crest and the presence of faults near by leave some doubt as to the best location for a test well. As the plane of the fault to the east dips southwestward, any test well should probably be as far from it as possible and yet be near the crest of the anticline. Presumably it is also advisable to keep away from the fault in sec. 16, because its northwestern extremity is not definite. With the above factors in mind, the most promising locality appears to be the SW. ¼ SW. ¼ sec. 9, T. 16 N., R. 8 E. If oil or gas in paying quantities is found in this locality, any additional producing territory will probably include most of the W. ½ sec. 9 except its northeasternmost part, the E. ½ sec. 8, the NE. ¼ sec. 17, and the NW. ¼ sec. 16.

If a well is drilled in the SW. ¼ SW. ¼ sec. 9, as above mentioned, the Layton sand, if it extends into this region, will probably be found at about 400 feet below sea level, or at a depth of about 1,250 to 1,300 feet. Inasmuch as the distance between the Layton and Bartlesville sands in the Cushing field varies from place to place, any estimate as to the depth of the Bartlesville may differ from the true depth, if that sand exists here, by several hundred feet. The distance between these sands as given in the record of a well in sec. 10,

T. 16 N., R. 7 E., is about 1,375 feet, and if this is the interval in the SW. ¼ sec. 9, T. 16 N., R. 8 E., the Bartlesville should be found there at 1,775 feet below sea level, or at a depth of about 2,600 to 2,650 feet; but it may be necessary, on account of the variation in the distance between the sands, to go several hundred feet deeper.

NORTH CATFISH ANTICLINE.

The North Catfish anticline lies in secs. 28, 29, 32, and 33, T. 17 N., R. 8 E., and in the northeastern part of sec. 5, T. 16 N., R. 8 E., and is described in detail on pages 82–83. As the highest part of this anticline is adjacent to the fault in sec. 5, the possible effect of this fault on the accumulation of oil and gas must be considered. The fault plane may have acted as a channel for the escape of any oil or gas which might have been in the sands that were broken, but no evidence of such escape was observed at the surface. Oil and gas, however, could have escaped along the fault plane even if none reached the surface, for they may have entered some other porous sand below the surface. (See fig. 18.) If the fault plane did not permit the escape of oil or gas originally confined in the anticline, it should have made the area immediately northeast of the fault a place for the accumulation of any oil or gas which the sands may have contained, by sealing them in. If such are the conditions the place for a well to obtain the greatest possible production, provided the sands are continuously porous and well stored, is at the highest part of the block on the northeast side of the fault, in the northeastern part of the NE. ¼ NW. ¼ or the northeastern part of the SW. ¼ NE. ¼ sec. 5, T. 16 N., R. 8 E. As the fault plane dips to the southwest it will not be penetrated by any wells drilled to the northeast of its trace at the surface.

If the fault does not seal the sands here and a test well drilled at this point proves a failure, the area to the north, which lies west of the slight reversal of dip, should not be condemned but should be tested by a second well drilled in the SE. ¼ sec. 32, T. 17 N., R. 8 E., preferably near the center or in the north half of this quarter section.

The position of the Layton and Bartlesville sands at these localities—the north-central part of sec. 5, T. 16 N., R. 8 E. and the center of the SE. ¼ sec. 32, T. 17 N., R. 8 E.—should be, respectively, about 30 or 40 feet more and 10 or 20 feet less than those given above for sec. 9, T. 16 N., R. 8 E.

LOCALITIES OF POSSIBLE FAVORABLE STRUCTURE.

MINOR ANTICLINES.

The possibilities of the anticline in sec. 18, T. 17 N. R. 10 E., appear uncertain. Because the unknown factors mentioned on pages 83 and 85 are so numerous, no specific location for a test well will be recommended. However, it is suggested that the crest of the anticline has the best possibilities. In view of the fact that the main (eastern) fault to the east probably dips to the southwest, a test well, to avoid passing through the fault, should be as far southwest of it as possible and still be near the crest of the anticline. Such a test would probably reach the Fort Scott limestone at about 1,000 feet below sea level; an oil and gas sand reported in the well in sec. 1, T. 16 N., R. 9 E. (see log on p. 97) at 1,170 feet; the Red Fork sand at 1,474 feet; and the Glenn sand at 1,640 feet.

Of the smaller anticlines whose reversed dips appear to be due to folding that accompanied the dropping of a fault block, the one in secs. 1 and 12, T. 16 N., R. 9 E., has been tested by a well drilled during the winter of 1915–16 by the Atlas Oil Co., near the south line of sec. 1. This well, whose log is given on page 97, is said to have found oil and gas at several horizons, as follows: 3,000,000 cubic feet of gas at 788 feet, a little gas at 1,065–1,083 feet; 1,000,000 cubic feet of gas at 1,145 feet, a showing of oil and gas at 2,040–2,074 feet, and a light showing of oil at 2,344–2,369 feet. The quantity of gas discovered was not considered sufficient to make it a paying gas well, and hence the hole was abandoned. From this meager showing of a well favorably located for such a structure, it would appear that this anticline is not sufficiently closed to the southeast to confine either oil or gas in large quantities. Considering the failure of this well, the prospects offered by similar folds in this area are not full of promise. There probably will come a time, however, when small producing wells will pay, and to find them the oil producer will drill all these minor folds that offer any promises of success. It is believed that the folds in sec. 30, T. 17 N., R. 9 E., sec. 14, T. 17 N., R. 8 E., sec. 21, T. 17 N., R. 8 E., and sec. 22, T. 16 N., R. 8 E., will give better chances than most of the surrounding territory.

The locality that appears best for a test of the anticline in sec. 30, T. 17 N., R. 9 E., is the center of the section. Not only is there a slight fold here, but the fault to the east may help influence the accumulation of oil or gas at this place, in the way described on pages 88 and 92. In drilling at this locality the strata that were found in the well in sec. 29, T. 17 N., R. 9 E. (see record on p. 95), will be found about 60 feet lower with reference to sea level.

The best locality for a first test of the anticline in sec. 14, T. 17 N., R. 8 E., is probably in the NE. ¼ SW. ¼. The fault to the east of this locality also may have some influence in causing oil and gas to accumulate. A guide as to what may be found here is afforded by the log of the well in sec. 26, T. 17 N., R. 8 E. (see p. 95), and the formations will be found about 20 to 30 feet lower with reference to sea level.

The fold in sec. 21, T. 17 N., R. 8 E., may first be tested by a well in the center of the NW. ¼. As the fault to the east is small, its influence in causing oil and gas to accumulate is probably negligible. The strata to be found here will probably be the same as those encountered in the wells in sec. 20, T. 17 N., R. 8 E., but at this locality they will probably be about 50 feet higher with respect to sea level. The records of these wells are given on pages 93–94.

For the anticline in sec. 22, T. 16 N., R. 8 E., the NW. ¼ SE. ¼ appears to be the most favorable locality for a test well. The displacement of the fault to the east is small, and its confining effect in causing oil and gas to accumulate here is probably also small. Some idea of the strata to be found here may be obtained by consulting the records of the wells in sec. 30, T. 16 N., R. 8 E., and sec. 3, T. 16 N., R. 8 E., which are given on page 94. The strata recorded in the well in sec. 30, T. 16 N., R. 8 E., should be found from 125 to 175 feet higher with reference to sea level, but those of the well in sec. 3, T. 16 N., R. 8 E., will be found at about the same position here.

The occurrence of several other folds whose form or even actual presence is questionable is mentioned on page 84. As the representations of these folds on the contour map are not based on well-determined facts, no suggestions for testing them will be given.

FAULTS.

The effectiveness of simple faults in causing oil and gas accumulations has not been well demonstrated in the Mid-Continent field. The faults of the Bristow region are small, and it may be that they affect only the rocks near the surface and do not reach the oil and gas bearing sands. Furthermore, they do not break the strata at right angles to the dip but at a small acute angle; hence, even if they do reach the oil and gas sands, their effectiveness in causing the oil and gas to accumulate is not at its maximum. Because the possibilities of finding paying quantities of oil and gas on the down dip (west) side of the faults are uncertain, search for such possible accumulations is not recommended until the more favorable areas of the Bristow region have been tested and their value proved.

LOCALITIES OF UNFAVORABLE STRUCTURE.

The localities of unfavorable structure in this region are those outside of the faulted zones and anticlines, in which the rock beds have the normal westward dip. The sands in the areas of normal structure probably carry some oil and gas in quantities sufficient to give showings in wells that penetrate them, but it requires some special feature, similar to those described on pages 88–89, to produce any accumulation large enough to pay for its development.

In the southeastern part of sec. 36, T. 17 N., R. 9 E., the structure seems to be normal, but sufficient gas was encountered in a well at a depth of 990–1,018 feet to make it worth while to close it in and save it for utilization at some future time. This is the only one of 13 wells drilled in the areas of normal structure in this region that found paying quantities of either oil or gas. For the locating of similar small paying wells no help can be expected from a study of the surface geology, and the chances for finding in this region other paying localities similar to the one mentioned appear small.

WELL RECORDS.

The wells whose records are given below are either in the area described in this report or in its immediate vicinity.

Log of P. M. Kerr's Elijah Hendrickson well No. 1, in the northwest corner E. ½ SW. ¼ sec. 5, T. 17 N., R. 8 E.

[From M. J. Munn; authority, P. M. Kerr. Casing: 12½-inch, 2 joints; 10-inch, 780 feet; 8¼-inch, 1,590 feet.]

	Depth.		Depth.
	Feet.		*Feet.*
Layton sand (small show for oil)	1,450–1,548	Wheeler sand (dry)	2,220–2,255
Jones sand (small show for oil)	1,790–1,808	Bartlesville sand (gas)	2,620–2,700
Cleveland sand (dry)	1,900–1,910	Tucker sand (water)	2,800–2,812

Log of U. Logan well No. 1, in the NW. ¼ sec. 20, T. 17 N., R. 8 E.

[From Bermont Oil Co. Contractor, American Drilling Co. Drilled Nov. 7, 1912, to May 16, 1913. Casing 20-inch, 19 feet; 16-inch, 57 feet; 12½-inch, 625 feet; 10-inch, 990 feet; 8¼-inch, 1,479 feet.]

	Depth.		Depth.
	Feet.		*Feet.*
Sand	907–946	Sand (little oil)	1,805–1,920
Lime (sprayed oil at 1,400 feet)	1,390–1,412	Wheeler sand (no oil)	2,270–2,320
Layton sand (no oil)	1,440–1,470	Oswego lime (no oil)	2,380–2,420
Sand	1,545–1,570		

Log of White & Sinclair's Capadenna Cox well No. 1, in southwest corner sec. 20, T. 17 N., R. 8 E.

[From R. C. McClellan, driller. Drilled July 12 to Aug. 31, 1915. Casing: 15½-inch, 36 feet; 12½-inch, 451 feet; 10-inch, 810 feet; 8-inch, 1,070 feet; 6-inch, 2,423 feet; $5\frac{3}{16}$-inch, 3,010 feet.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Water sand	10	70	Red rock	20	480
Red mud	40	110	Sand (water)	30	510
Sand	20	130	Blue mud	30	540
Red mud	30	160	Unrecorded	5	545
Sand (water)	20	180	Blue mud	55	600
Blue mud	70	250	Sand (water)	25	625
Sand (water)	10	260	Red rock	65	690
Red rock	40	300	Sand	10	700
Sand	20	320	Red rock	30	730
Red rock	30	350	Sand (water)	20	750
Sand (water)	25	375	Red rock	6	756
Red rock	50	425	Sand	14	770
Sand (water)	35	460	Lime	4	774

Log of White & Sinclair's Capadenna Cox well No. 1, in southwest corner sec. 20, T. 17 N., R. 8 E.—Continued.

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Sand (water)	16	790	Slate	34	1,534
Red rock	35	825	Sand (water, 20 bailers)	16	1,550
Lime (water)	5	830	Slate	170	1,720
Red rock	5	835	Lime	4	1,724
Sand (water)	25	860	Slate	93	1,817
Red rock	20	880	Lime	9	1,826
Lime	20	900	Jones sand	20	1,846
Red rock	75	975	Slate	134	1,980
Sand	25	1,000	Lime	16	1,996
Slate	15	1,015	Slate	429	2,425
Lime (gas and water)	15	1,030	Wheeler sand	75	2,500
Slate	45	1,075	Slate	40	2,540
Lime	5	1,080	Lime	10	2,550
Slate	20	1,100	Sand	95	2,645
Lime	8	1,108	Slate	55	2,700
Slate	17	1,125	Sand	50	2,750
Lime	5	1,130	Slate	120	2,870
Slate	70	1,200	Sand	30	2,900
Lime	12	1,212	Slate	90	2,990
Slate	253	1,465	Sand	45	3,035
Layton sand	35	1,500			

Log of Oklahoma Natural Gas Co.'s Daniel West well No. 1, in sec. 30, T. 16 N., R. 8 E.

[From Oklahoma Natural Gas Co. Drilling completed Oct. 16, 1913. Contractor, Kaw Drilling Co. Casing: 12½-inch, 309 feet; 10-inch, 801 feet; 8-inch, 1,285 feet.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Sand	50	50	Slate	70	1,100
Slate	35	85	Lime	10	1,110
Sand (hole full of water at 130 feet)	70	155	Sand	50	1,160
Red rock	125	280	Slate	130	1,290
Sand	20	300	Sand	40	1,330
Red rock	65	365	Slate	230	1,560
Sand (hole full of water at 365 feet)	75	440	Lime shells	40	1,600
Red rock	70	510	Slate	250	1,850
Sand	30	540	Sand (2 bailers of water per hour at 1,900 feet; show of oil)	115	1,965
Red rock	65	605	Slate	535	2,500
Sand	30	635	Slate and shells	223	2,723
Slate	25	660	Sand	12	2,735
Sand	25	685	Slate	115	2,850
Red rock	65	750	Brown shale	50	2,900
Sand	40	790	Slate	85	2,985
Slate	100	890	Lime	24	3,009
Sand (hole full of water at 890 feet)	120	1,010			
Lime	20	1,030			

Log of White & Sinclair's Johnny Myers well No. 1, in northeast corner SE. ¼ sec. 3, T. 16 N., R. 8 E.

[From White & Sinclair. Drilling completed May 28, 1913. Contractor, Kiester Drilling Co. Casing: 16-inch, 141 feet; 12½-inch, 355 feet; 10-inch, 856 feet; 8 inch, 1,406 feet; 6⅝-inch, 2,321 feet.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Sand (water at 2,360 feet)	20	2,374	Water	......	2,872
Shell	......	2,724	Total depth	......	2,875
Sand	80	2,810			

Log of Noble Cobb well No. 1, in sec. 26, T. 17 N., R. 8 E.

[From Bermont Oil Co.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
"Surface"	25	25	White shale	15	1,205
Quicksand (water)	15	40	Sand (10 bailers of water)	25	1,230
Red clay	50	90	Lime	5	1,235
Sand (water)	10	100	White shale	65	1,300
Red clay	20	120	Sand	27	1,327
Sand (water)	25	145	Brown shale	78	1,405
Red rock (water)	20	165	White slate	73	1,478
Sand	5	170	Sandy lime	10	1,488
Red rock	20	190	Shale	43	1,531
Sand	5	195	Lime	19	1,550
Soapstone	35	230	Sand	15	1,565
Sand	5	235	White slate	35	1,600
Blue shale	25	260	Black slate	30	1,630
Sand (water)	20	280	Sand	1	1,631
Red rock	55	335	White shale	4	1,635
Sand	5	340	Oil sand (show of oil)	20	1,655
Red rock	5	345	White shale	10	1,665
Lime (very hard)	10	355	Sand (little gas)	10	1,675
Red rock	15	370	White shale	25	1,700
Sand (water)	25	395	Lime	5	1,705
Break	2	397	Shale	120	1,825
Sand	54	451	Black shale	345	2,170
Red rock	39	490	Lime	4	2,174
Sand (water)	7	497	Shale	6	2,180
Break	2	499	Lime	25	2,205
Sand	10	509	Black slate	30	2,235
Break	3	512	Sandy lime	20	2,255
Lime	8	520	White shale	25	2,280
Broken lime	5	525	Sand	35	2,315
Slate	100	625	Sandy shale	25	2,340
Sand (show of gas)	20	645	Brown shale	30	2,370
Unrecorded	17	662	Sand	30	2,400
Brown shale	7	669	White shale	70	2,470
Sand (hole full of water)	11	680	Hard sand	10	2,480
Blue shale	45	725	White shale	80	2,560
Shell	5	730	Black shale	60	2,620
Brown shale	5	735	Lime	10	2,630
Lime	10	745	White shale	5	2,635
Blue shale	95	840	Sand	20	2,655
Lime	5	845	Gray shale	85	2,740
White slate	25	870	Black slate	17	2,757
Sand	5	875	Sandy lime (3 bailers per hour)	10	2,767
Blue slate	5	880	White shale	9	2,776
White slate	95	975	Broken sand	24	2,800
Slate	135	1,110	Water sand (hole full of water last three screws)	78	2,878
Sandy shale	20	1,130			
Lime	60	1,190			

Log of B. B. Jones and Hoppy Toad Oil Co.'s Maxey well No. 1, in sec. 29, T. 17 N., R. 9 E.

[From C. T. Freeland and Glen Craker. Drilled November, 1913, to January, 1914. Contractors, Freeland & Craker. Casing: 12½-inch, 338 feet; 10-inch, 852 feet; 8-inch, 1,340 feet.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
"Surface"	4	4	Lime (hole full of water)	30	500
Sand	7	11	Slate	20	520
Slate	29	40	Lime	15	535
Lime (water)	20	60	Slate	35	570
Red mud	40	100	Sand (water)	5	575
Lime	20	120	Lime	20	595
Sand	25	145	Sand	8	603
Slate	65	210	Lime	7	610
Sand (water)	30	240	Slate	40	650
Red rock	60	300	Lime	5	655
Lime	38	338	Slate	95	750
Sand	62	400	Lime	35	785
White lime	30	430	Break	2	787
Slate	40	470	Lime	13	800

Log of B. B. Jones and Hoppy Toad Oil Co.'s Maxey well No. 1, in sec. 29, T. 17 N., R. 9 E.—Continued.

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Sand	5	805	Sandy shale	90	1,830
Shale	7	812	Slate	75	1,905
Sand	40	852	Sand	10	1,915
Slate	6	858	Slate	45	1,960
Lime	6	864	Dark shale	60	2,020
Slate	36	900	Lime	50	2,070
Slate, shelly	70	970	Dark shale	20	2,090
Lime	35	1,005	Lime, Baker sand (dry)	10	2,100
Slate	25	1,030	Shale	80	2,180
Sand (11 bailers of water)	50	1,080	Sand	5	2,185
Light shale	20	1,100	Shale	80	2,265
Black shale	207	1,307	Wheeler sand	40	2,305
Sand	33	1,340	Shale	50	2,355
Light shale	5	1,345	Sand	15	2,370
Sand	5	1,350	Shale	110	2,480
Dark shale	12	1,362	Sand	35	2,515
Lime	6	1,368	Shale	40	2,555
Layton sand (show of oil at 1,368–1,380 feet)	39	1,407	Black shale	10	2,565
Shale	8	1,415	Bartlesville sand; top hard (show of oil at 2,640–2,646 feet; 1 bailer of oil after standing over Sunday)	85	2,650
Lime	10	1,425	Shale	10	2,660
Slate, shelly	55	1,480	Water sand	40	2,700
Slate	20	1,500			
Sand	30	1,530			
Shale	210	1,740			

Log of Hoppy Toad Oil Co.'s Joseph Bell well No. 1, in sec. 33, T. 17 N., R. 9 E.

[From Bermont Oil Co. Casing: 8¼-inch, 1,564 feet.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Red rock	130	130	Sand	10	1,490
Sand	15	145	Sand (10 bailers of water)	10	1,500
Red rock	25	170	Sand	75	1,575
Sand	78	248	Lime	43	1,618
Lime	17	265	Slate	182	1,800
Red rock	13	278	Black slate (cave)	100	1,900
Sand	12	290	Slate	150	2,050
Red rock	15	305	Cave	25	2,075
Sand	15	320	Slate	5	2,080
Red rock	10	330	Lime	8	2,088
Slate	78	408	Slate	4	2,092
Lime	52	460	Lime	20	2,112
Red sand	20	480	Slate	6	2,118
Lime	10	490	Sand	38	2,156
Water sand	25	515	Slate	64	2,220
Lime	41	556	Hard lime	7	2,227
Brown sand	6	562	Slate	29	2,256
Slate	89	651	Wheeler sand	10	2,266
Lime	7	658	Black shale	66	2,332
Slate	94	752	Sand	30	2,362
Sand (enough water to drill with at 777 feet)	30	782	Black shale	78	2,440
Slate	78	860	Black cave	60	2,500
Sand (hole full of water)	35	895	Sand	5	2,505
Slate	75	970	Shale	5	2,510
Lime	30	1,000	Sand	52	2,562
Slate	40	1,040	Lime shell	3	2,565
Sand	10	1,050	Sand	36	2,601
Slate	160	1,210	Sandy shale	6	2,607
Black shale	58	1,268	White shale	27	2,634
Slate	73	1,341	Black shale	10	2,644
Lime and sand	10	1,351	Sand (top hard)	13	2,657
Slate	39	1,390	Sandy shells	38	2,695
Lime	8	1,398	Sand (1½ bailers of water)	30	2,725
Slate	77	1,475	Unrecorded	6	2,731
Sand (gas and oil)	5	1,480	Sand (hole full of water at 2,737 feet; through sand)	19	2,750

Log of Selby Oil Co.'s and Frank Barnes's Stubblefield well No. 1, in the SW. ¼ SW. ¼ sec. 10, T. 16 N., R. 9 E.

[From C. T. Freeland and Glen Craker. Casing: 10-inch, 453 feet; 8¼-inch, 800 feet.]

	Thickness.	Depth.
	Feet.	*Feet.*
Red quicksand	50	50
Red rock	20	70
Sand (water)	20	90
Red rock	30	120
Sand	50	170
Shale	80	250
Sand	15	265
Red rock	15	280
Sand (this may be the Tiger Creek sandstone)	35	315
Slate	75	390
Sand	55	445
Unrecorded	265	710
Sand (hole full of water)	35	745
Unrecorded	105	850
Lime (show of water)	12	862
Unrecorded	338	1,200
Lime	10	1,210
Unrecorded	50	1,260
Sand	22	1,282
Unrecorded	38	1,320
Sand	5	1,325
Unrecorded	30	1,355
Sand	5	1,360
Unrecorded	55	1,415
Sand (little gas)	5	1,420
Unrecorded	5	1,425
Sand shells	15	1,440
Sandy lime	20	1,460
Slate	160	1,620
Black slate	20	1,640
Slate	200	1,840
Black slate	20	1,860
Slate	40	1,900
Hard lime shell	2	1,902
Unrecorded	178	2,080
Lime	15	2,095
Unrecorded	30	2,125
Lime	5	2,130
Unrecorded	80	2,210
Red rock (little gas)	30	2,240
Unrecorded	90	2,330
Black shale, caved	58	2,388
Sand	12	2,400
White sandy shale	110	2,510
Black slate.		

Log of Atlas Oil Co.'s Allan Ralston well No. 1, in SW. ¼ sec. 1, T. 16 N., R. 9 E.

[From Harry R. Johnson. Drilling began Dec. 30, 1915. Casing: 10-inch, 826 feet; 8¼-inch, 1,648 feet.]

	Thickness.	Depth.
	Feet.	*Feet.*
Dirt	4	4
Sand	31	35
Mud (red and blue)	115	150
Water sand (12 bailers fresh water per hour)	45	195
Black shale (mud)	86	281
Lime	49	330
Shale	30	360
Lime	15	375
Shale	65	440
Water sand (5 bailers at 443 feet)	30	470
Shale (hole full of water)	98	568
Sand	12	580
Shale	124	704
Hard lime	8	712
Shale	15	727
Lime	7	734
Shale	46	780
Sand (3,000,000 feet of gas at 788 feet)	20	800
Black shale	265	1,065
Sand (light gas)	18	1,083
Shale	27	1,110
Lime	7	1,117
Shale	24	1,141
Sand (1,000,000 feet of gas at 1,145 feet)	30	1,171
Shale	60	1,231
Sand	14	1,245
Shale	95	1,340
Sand	7	1,347
Shale	33	1,380
Sand	6	1,386
Shale	414	1,800
Sand	8	1,808
Shale	62	1,870
Lime (Big lime)	25	1,895
Shale	5	1,900
Sand, limy	18	1,918
Shale	65	1,983
Lime (Oswego)	8	1,991
Shale	49	2,040
Sand (show of oil and gas)	34	2,074
Shale	11	2,085
Lime shell	5	2,090
Shale	55	2,145
Sand	8	2,153
Shale	191	2,344
Sand (light show of oil)	25	2,369
Shale	81	2,450
Shell	10	2,460
Shale	40	2,500
Sand (hole full of water at 2,535 feet)	62	2,562
Cave	29	2,591
Lime shell	15	2,606
Cave	18	2,624
Shale	234	2,858
Cave	30	2,888
Black shale	32	2,920
Hard lime	30	2,950
Shale	40	2,990
Broken lime	5	2,995
Lime	183	3,178

Log of Oklahoma Natural Gas Co.'s John F. Ralston well No. 1, in sec. 6, T. 16 N., R. 10 E.

[From Oklahoma Natural Gas Co. Drilled Dec. 1, 1910, to Feb. 4, 1911. Casing: 12½-inch, 52 feet; 10-inch, 450 feet; 6⅝-inch, 2,420 feet.]

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and dirt	15	15
Quicksand	37	52
Slate	38	90
Sand	5	95
Slate	235	330
Sand (2 bailers of water at 330 feet; 5 bailers of water per hour at 340 feet)	10	340
Slate	85	425
Sand (hole full of water at 440 feet)	15	440
Slate	515	955
Sand (gas at 960 feet)	60	1,015
Slate	121	1,136
Sand (3 bailers of water per hour at 1,150 feet)	59	1,195
Slate	19	1,214
Limestone	83	1,297
Slate and shells	568	1,865
Sand	15	1,880
Slate	80	1,960
Sand	10	1,970
Slate	305	2,275
Sand	15	2,290
Slate	95	2,385
Sand (hole full of water at 2,418 feet)	33	2,418
Slate	259	2,677
Sand shell (oil at 2,678 feet)	1	2,678
Slate and shells	122	2,800
Limestone	202	3,002

Log of Oklahoma Natural Gas Co.'s Bertha M. Self well No. 1, in sec. 36, T. 17 N., R. 9 E.

[From Oklahoma Natural Gas Co. Drilled Mar. 18 to Apr. 5, 1911. Contractor, Charles McKeever. Casing: 12½-inch, 38 feet; 10-inch, 453 feet, 8-inch, 530 feet.]

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	20	20
Quicksand	18	38
Sand (water)	97	135
Unrecorded	265	400
Sand	10	410
Unrecorded	70	480
Sand (water at 485 feet)	10	490
Unrecorded	80	570
Lime	10	580
Unrecorded	110	690
Lime	10	700
Sand (gas at 990–1,010 feet)	....	1,018

Log of Oklahoma Natural Gas Co.'s Henry A. Self well No. 1, in sec. 30, T. 17 N., R. 10 E.

[From Oklahoma Natural Gas Co. Drilled June 8 to Aug. 28, 1911. Casing: 12½-inch, 58 feet; 10-inch, 475 feet; 8¼-inch, 1,175 feet; 6⅝-inch, 2,359 feet.]

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and quicksand	58	58
Slate and shells (3 bailers of water at 155 feet)	192	250
Sand shell (2 bailers of water at 252 feet)	5	255
Slate	75	330
Sand (10 bailers of water at 335 feet)	20	350
Sand (hole full of water at 365 feet)	55	405
Unrecorded	155	560
Sand (6 bailers of water at 565 feet)	16	576
Unrecorded	298	874
Sand	36	910
Unrecorded	90	1,000
Cave	50	1,050
Unrecorded	85	1,135
Sand (6 bailers of water at 1,150 feet)	41	1,176
Lime	458	1,634
Unrecorded	112	1,746
Oswego lime	6	1,752
Unrecorded	123	1,875
Sand	30	1,905
Unrecorded	149	2,054
Sand	16	2,070
Unrecorded	158	2,228
Sand	131	2,359
Unrecorded	2	2,361
Cave	2	2,363
Lime shell	2	2,365
Unrecorded	330	2,695
Sand	105	2,800

Log of Oklahoma Natural Gas Co.'s Jake Brown well No. 1, in sec. 20, T. 17 N., R. 10 E.

[From Oklahoma Natural Gas Co. Drilled June 29 to Aug. 2, 1912. Contractor, Braden Drilling Co. Casing: 12½-inch, 465 feet; 10-inch, 1,400 feet; 8¼-inch, 1,625 feet; 6⅝-inch, 2,230 feet.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
"Surface"	20	20	Slate	204	2.029
Sand	100	120	Shell	6	2,035
Slate and shells	280	400	Slate	65	2,100
Sand (hole full of water at 400 feet)	35	435	Red Fork (top streak sand; 180,000 cubic feet of gas at 2,109 feet; small show of oil at 2,115 feet)	25	2,125
Slate	565	1,000	Slate	5	2,130
Slate and lime shell	100	1,100	Red Fork (second sand)	20	2,150
Slate	100	1,200	Slate	87	2,237
Sand (small amount of gas at 1,210 feet)	50	1,250	Glenn sand (water at 2,240 feet in Glenn sand)	12	2,249
Slate	400	1,650			
Big lime	65	1,715			
Slate	85	1,800			
Sand (2 barrels of water per hour at 1,800 feet)	25	1,825			

Log of Oklahoma Natural Gas Co.'s Kelly Yellowhead well No. 1, in sec. 32, T. 17 N., R. 10 E.

[From Oklahoma Natural Gas Co. Drilled Sept. 2 to Oct. 30, 1912. Contractor, Braden Drilling Co. Casing: 10-inch, 481 feet; 8¼-inch, 1,186 feet; 6⅝-inch, 2,368 feet.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	5	5	Broken lime	10	1,585
Shale	15	20	Hard lime	4	1,589
Lime	10	30	Shale	11	1.600
Break	5	35	Lime shell	3	1,603
Lime	10	45	Shale	27	1,630
Shale	15	60	Light shale	10	1,640
Shale and shell	65	125	Lime	8	1,648
Broken lime	15	140	Shale	98	1,746
Shale	60	200	Sandy shale	10	1,756
Lime	15	215	Lime, hard	7	1,763
Break (water)	5	220	Shale	118	1.881
Sand	15	235	Sand (show of oil)	18	1,899
Shale, lime, and shell	75	310	Black shale	216	2,115
Sand (water)	15	325	Dark sand	15	2,130
Shale	5	330	Shale	68	2.198
Sand, hard	95	425	Lime	4	2,202
Shale	60	485	Broken lime	10	2,212
Lime	12	497	Shale	18	2,230
Shale and shells	133	630	Sand (water)	138	2 368
Lime	20	650	Shale	6	2,374
Light shale	45	695	Sand, hard	22	2,396
Lime	5	700	Shale	4	2,400
Light shale	175	875	Lime, hard	12	2,412
Lime	12	887	Shale	88	2,500
Light shale	111	998	Lime, hard	8	2,508
Lime	4	1,002	Shale	12	2,520
Shale	103	1,105	Lime	4	2,524
Lime, shale, and shells	20	1,125	Black shale	21	2,545
Sandy shale	10	1,135	White shale	35	2,580
Sand (hole full of water)	33	1,168	Black shale	110	2,690
Shale	10	1,178	Lime	25	2,715
Broken lime	35	1,213	Shale	40	2,755
Shale	362	1,575	Lime	17	2,772

THE DE SOTO-RED RIVER OIL AND GAS FIELD, LOUISIANA.

By G. C. MATSON and O. B. HOPKINS.

LOCATION.

The De Soto-Red River oil and gas field lies in De Soto and Red River parishes, La., in the northwestern part of the State, in Tps. 12 and 13 N., Rs. 10, 11, 12, and 13 W. Louisiana meridian. It is 30 miles southeast of Shreveport, the principal business and railroad center in the northwestern part of the State, and extends from a point near Naborton in a northeasterly direction across Red River to Crichton, on the line of the Louisiana Railway & Navigation Co. The east end of the field is accessible also over the Natchitoches branch of the Texas & Pacific Railway, which follows the west bank of Red River and crosses the field near Abington. Naborton, the center of development in the western part of the field, may be reached over the Frost-Johnson Lumber Co.'s branch road from Mansfield. In relation to the neighboring productive fields of Louisiana, the De Soto-Red River field is 45 miles slightly east of south of the Caddo oil and gas field, 30 miles south of the Shreveport gas field, and 12 miles north of the small oil pool near Pelican. (See Pl. VII.)

HISTORY.

The development of the Caddo field, which began in 1904, and the drilling of large gushers there some years later called the attention of oil prospectors to northwestern Louisiana as favorable territory. Drilling in and near the area called by Harris[1] the Sabine uplift finally led, in 1912, to the discovery of gas in De Soto Parish near Naborton at a depth of about 800 feet, or about the same depth as the shallow gas wells of the Caddo field. The locations of some of the gas wells were selected by J. Y. Snyder after field observations of the local structure.

The presence of the gas-bearing Nacatoch sand in De Soto Parish and the belief that deeper productive sands corresponding to those in Caddo Parish were also present led to deep drilling, which resulted in the discovery of small quantities of oil, and on May 10, 1913, the completion of the Gulf Refining Co.'s Jenkins well No. 2 proved the presence of a notable oil pool. Within a few months all the large oil companies operating in northern Louisiana had become active here, and during the following 12 months the Naborton district experienced its greatest activity.

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[1] Harris, G. D., Oil and gas in Louisiana: U. S. Geol. Survey Bull. 429, p. 27 (map), 1910.

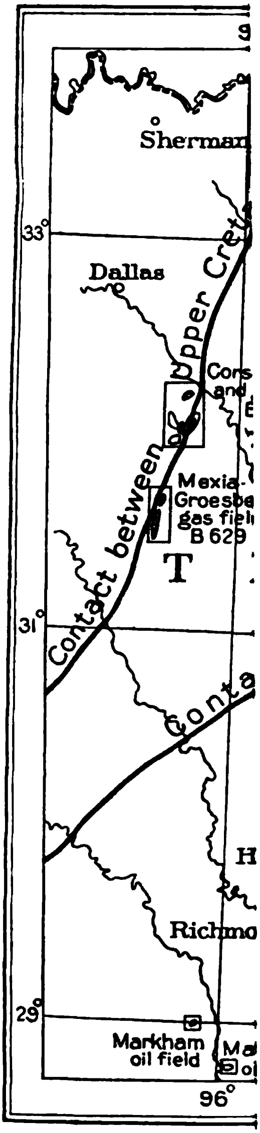
In the Abington district of Red River Parish the discovery well, Marston No. 1, was drilled in April, 1914. By the fall of that year the center of interest had moved from Naborton to the northeastern continuation of the field, where leasing and drilling became active. In November, 1914, the first well was completed in the Crichton district, on the east side of Red River. Interest in this extreme northeast end of the field was brought to a climax by the completion of a large gusher on the Weiss property, in sec. 18, T. 13 N., R. 10 W., on January 27, 1915. The Crichton district was the center of activity during 1915, and in it one of the most productive oil pools in the United States has been developed.

FIELD WORK.

During the spring of 1913, before the discovery well in De Soto Parish had been completed, G. C. Matson made a short trip to this field and outlined the general structural features. With the view of obtaining more detailed knowledge of the structure and of the occurrence and distribution of oil and gas, he returned in the autumn of 1914, and with O. B. Hopkins and E. H. Finch spent part of November and most of December and January making a survey of the district.

In general, the field work consisted in collecting data from exposures of the strata and information concerning development work, such as well logs, altitudes of the wells, and well samples, It was not possible to outline the structure of the entire field from the well logs alone, because they were not uniformly distributed over it; neither was it possible to make a satisfactory structural map of the entire field from the rock exposures, as in more than half of the area no rocks are exposed. Consequently it was necessary to collect all available data from both sources.

Stadia traverses and level lines were carried over the field in order to locate the exposures and determine their altitudes. There are no key rocks exposed at the surface which can be traced over the field and from which the structure can be unraveled; furthermore, it is not possible to trace a particular horizon over any considerable area, as the exposures are too poor and the lithology too varied. Consequently it was necessary in determining the dip to use different beds



INDEX MAP OF A

or horizons in different parts of the field, such as the contact between a sand and clay bed, a particular bed of clay, or a sandstone ledge.

ACKNOWLEDGMENTS.

So many citizens of northwestern Louisiana have contributed material for use in this report or have assisted the authors in other ways that it is impossible to mention all of them. Special acknowledgments are due to the officials of the oil companies operating in the field for maps showing locations of wells, lists of altitudes, and logs of wells. The following list, which is far from complete, contains the names of those to whom the authors desire to express special thanks: W. B. Pyron, O. A. Wright, Judge R. E. Brooks, A. G. Curtis, M. B. Carmody, C. D. Keen, William C. Wolfe, S. A. McCune, J. C. McCue, W. C. Ribb, C. C. Averrill, George Beard, S. S. Hunter, W. B. McCormick, R. B. Allison, Sam Mason, McCann & Harper, and J. S. Richardson.

The following geologists and engineers have not only furnished valuable information but also offered suggestions that were useful in the prosecution of the field work: Mowry Bates, E. G. Woodruff, L. C. Chapman, J. Y. Snyder, F. E. Chalk, C. M. Bennett, L. B. Philip, and J. W. Anderson.

The manuscript for this report has been read by E. W. Shaw and G. S. Rogers, geologists of this Survey, and the authors desire to express appreciation for their helpful criticism.

TOPOGRAPHY.

The De Soto-Red River oil and gas field is in what have been called the "hill parishes" of Louisiana. It extends from the hills of De Soto Parish eastward across the broad valley of Bayou Pierre and Red River to the hills in Red River Parish beyond the river. (See Pl. VIII, in pocket.) Approximately half of the field, as outlined, is in the hills to the west of the valley, and the other half is in the broad valley itself. The width of the valley decreases from about 8 miles in the northern part of the area to 5 miles in the southern part. The greater width to the north is due to the greater area covered by old Bayou Pierre Lake, which is now drained.

Topographically the area may be conveniently divided into three parts—the low lands along Bayou Pierre and Red River, the area of comparatively level land between the low lands and the hills, and the hilly region. The first division consists of comparatively recent stream terraces. The lowland on the east side of Red River in the neighborhood of Crichton ranges from 130 to 135 feet in altitude; on the west side of the river near the Marston wells the general altitude is between 150 and 155 feet. Farther west along the margin of old Bayou Pierre Lake the altitude is about 140 feet.

From the low area mentioned above the country rises gradually toward the west to a well-defined plain which has an altitude of 190 to 210 or probably 220 feet along the tributary streams. This plain, though somewhat dissected, is well developed; in the northeast corner of T. 12 N., R. 12 W., east of Naborton; in the southeast corner of T. 13 N., R. 12 W.; and in sec. 32, T. 12 N., R. 11 W., along the Naborton and Seven Forks road south of the Lakeside wells. It is on the surface of this plain that the so-called "gas mounds" are most prominent. Little information about the structure can be gained from a study of this comparatively flat area, for although the underlying strata are exposed over the greater part of it the exposures are poor. Along the eastern edge of the field, however, there is a bluff which separates the low bottom lands from this higher plain, and along it there are some exposures that are useful for determining the structure of the underlying formations.

The highest hills in the field rise a little more than 400 feet above sea level, the range in altitude or relief being therefore little more than 250 feet. In view of this slight relief, the hilly district is particularly rough, especially in the region of the Dolette Hills, in the south-central part of the district. These hills have been carved by small streams, which carry little or no water except in rainy seasons, into V-shaped hollows with steep slopes. The slopes bordering the broad, flat bottoms of the large streams are equally steep. Owing to the thick covering of vegetation and the widespread mantle of sand, the exposures of the underlying strata are not good even on the steep slopes and in the bottoms of the deep ravines.

GEOLOGY.

STRATIGRAPHY.

GENERAL FEATURES.

The alternating beds of sand, shale, limestone, clay, etc., that form the Coastal Plain dip gently seaward but at a greater angle than the general slope of the country; thus the older beds gradually disappear under more recent ones and become progressively more deeply buried toward the coast. As the dip is slight, the outcrops of the various beds, or the formations into which they are divided, are relatively wide, and in any particular locality only a small section of the strata that form the Coastal Plain can be seen at the surface. This is particularly true of the Sabine uplift, an area over which the beds, except for small irregularities, are almost horizontal, so that only one formation is exposed at the surface, with remnants of a thin covering of recent deposits. The De Soto-Red River field, which is on the Sabine uplift, is thus at a considerable distance from the surface outcrops of strata that underlie the field at no great depths. The variations in lithology and thickness of the different formations, both along the outcrops and particularly from the ancient shore line seaward, make the correlation of the formations from well records, where fossils are not available, very difficult and in places impossible. Although it is safe to assume that the older formations which crop out to the northwest and north, in Texas and Arkansas, underlie this field, the beds shown in the well logs of De Soto and Red River parishes can be correlated only tentatively with the strata as studied and divided into formations along the outcrops, and for some well logs even this can not be done, because the information supplied by the logs is not sufficient. Good samples are not easily obtainable where the rotary method of drilling is used, because fragile shells are ground up by the drill and the material from the bottom of the hole is mixed with the material washed from its walls.

In the following table is given a list of the formations into which the strata of the field are divided on the basis of their surface outcrops in Louisiana and adjoining States:

Generalized section of formations supposed to underlie the De Soto-Red River oil field, La.[a]

System.	Series.	Group.	Formation.
Quaternary.	Recent.		
	Pleistocene.		
Tertiary.	Eocene.		Wilcox formation. Midway formation.
Cretaceous.	Gulf (Upper Cretaceous).		Arkadelphia clay. Nacatoch sand. Marlbrook marl.
		Austin.	Annona chalk. Brownstown marl.
			Eagle Ford shale (including Blossom sand member). Woodbine sand.
	Comanche (Lower Cretaceous).	Washita.	Denison formation. Fort Worth limestone. Preston formation.
		Fredericksburg.	Goodland limestone.
			Trinity sand.

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[a] The Upper Cretaceous formations do not crop out in the De Soto-Red River field and are known from well logs only. The Lower Cretaceous formations have not been reached in the wells of this field, but the formations enumerated in the table probably underlie the field.

In the De Soto-Red River field only the Wilcox formation and the Pleistocene and Recent deposits are found at the surface; the lower formations down to the Woodbine sand are known from well records only. It is probable that no wells have penetrated the Lower Cretaceous in this field. In the following discussion brief descriptions of the thickness and lithologic character of the different formations at their nearest known localities are given and tentative correlations suggested so far as possible. The Nacatoch sand is the most easily recognizable unit in the logs of the wells of this and adjoining regions. The "chalk," which includes the Marlbrook and Annona and part or all of the Brownstown, is recognizable as a whole over a large area but is inseparable into formations.

CRETACEOUS SYSTEM.

COMANCHE SERIES (LOWER CRETACEOUS).

The presence of beds of Lower Cretaceous age in southern Arkansas and northeastern Texas, together with the fact that they are known to pass beneath the younger formations toward the south, makes it safe to infer that these formations are present in the De Soto-Red River field, though they are so deeply buried there that even the uppermost formation of this age may not have been reached by the oil and gas wells. In the absence of definite information concerning the character of the materials in these beds, it is difficult to tell in advance of drilling their nature and thickness. In southern Arkansas and northeastern Texas the Lower Cretaceous has been divided into the Trinity, Fredericksburg, and Washita groups, named in the order of their age, beginning with the oldest. In that region the Trinity group is represented by sand alone and is known as the Trinity sand, but farther southwest in Texas it includes two sands separated by about 300 feet of limestone.

The Trinity sand was deposited on the older geologic formations after they had been subjected to considerable weathering and erosion, and the materials incorporated in its lower portion were derived from these older formations. It is probable that the lower portion of the Trinity in the De Soto-Red River field, if present there, is similar to the phases exposed in northeastern Texas, which, according to Gordon,[1] consist of quartz sand with scattered pebbles and boulders of quartz, lenses and layers of clay and remains of vegetable matter, together with fossil remains of animals that lived in brackish water.

In southwestern Arkansas the Fredericksburg group is represented by the Goodland limestone, which is 25 feet thick, but in northeastern Texas this group is thicker and contains some shale interbedded with

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[1] Gordon, C. H., Geology and underground waters of northeastern Texas: U. S. Geol. Survey Water-Supply Paper 276, p. 14, 1911.

the limestone. Two or three formations consisting of limestones and shales and having a thickness of several hundred feet constitute the Washita group in Texas and Oklahoma.

The total thickness of all the formations belonging to the Lower Cretaceous in the De Soto-Red River oil field is a matter of speculation, but at Dallas, in northeastern Texas, the thickness exceeds 1,300 feet, and the top of the Trinity group, as recognized there, is about 800 feet below the base of the Upper Cretaceous. Estimates of thickness based on published statements of the thickness of the different formations in southwestern Arkansas give the depth of the upper part of the Trinity group below the base of the Upper Cretaceous as scarcely more than half this amount.

GULF SERIES (UPPER CRETACEOUS).

The beds shown in the logs of wells in the De Soto-Red River field (see Pls. IX, X) are not readily separable into formations that can be correlated with those recognized in the well logs of the Caddo field and described from their outcrops in southwestern Arkansas and northeastern Texas. The Upper Cretaceous formations that have been recognized at their surface outcrops[1] in northeastern Texas are the Woodbine sand, Eagle Ford shale (including the Blossom sand member), Brownstown marl, Annona chalk, Marlbrook marl, Nacatoch sand, and Arkadelphia clay. The Nacatoch sand is the only one of these formations that can be recognized in well logs in the De Soto-Red River field, and for this reason exact correlations between the Upper Cretaceous formations of the two regions are impossible.

The Upper Cretaceous section in southwestern Arkansas differs from the one just given, the lower portion, including the Woodbine sand and Eagle Ford shale, with the Blossom sand member, being represented by beds of sand (the Bingen sand) having a total thickness of 500 feet.[2] That portion of the section in De Soto and Red River parishes that lies below the chalk resembles the Bingen sand, though it contains more clay and less sand.

WOODBINE SAND AND EAGLE FORD SHALE.

The lower portions of the sections penetrated in the wells in the De Soto-Red River field consist of shale and clay with many thin beds of sand and sandstone, 950 to 1,150 feet in total thickness. These beds include both the Woodbine sand and the Eagle Ford shale of the wells in the Caddo field,[1] together with some deeper beds of shales and sands that underlie a bed of hard limestone. It is difficult to obtain samples of this limestone from the drillings, because it is so hard that it is ground to a fine powder. It resembles in character some of the limestone beds in the upper part of the Lower Cretaceous but can not be correlated with them if the fossils that have been obtained from wells in this field came from the deep sands. The information on this subject is summarized in the discussion of the generalized section and the correlation of the sections in the De Soto-Red River and Caddo fields (pp. 113–116).

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[1] Matson, G. C., The Caddo oil and gas field, Louisiana and Texas: U. S. Geol. Survey Bull. 619, pp. 17–19, 1916. Harris, G. D., Oil and gas in Louisiana: U. S. Geol. Survey Bull. 429, p. 125, 1910.

[2] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, pp. 23–24, 1906.

BROWNSTOWN MARL, ANNONA CHALK, AND MARLBROOK MARL.

From 450 to 650 feet of chalk, containing thin beds of shale, is encountered in the wells in the De Soto-Red River field. This chalk is believed to represent the Brownstown marl, Annona chalk, and Marlbrook marl.[2] In some parts of Red River Parish a bed of shale from a few feet to 100 feet thick occurs between the chalk and the overlying Nacatoch sand, and this shale probably belongs to the Marlbrook marl.

NACATOCH SAND.

The Nacatoch sand is distinct from the calcareous shale and chalk below and the dark-colored shales above it. As a rule its base is more sharply defined than its top, owing to the fact that there are some thin sandy layers in what is supposed to be the base of the Arkadelphia. However, this sand and the chalk below are the most persistent and easy recognizable formations in the field. Of the two the sand can probably be most clearly recognized, for it is a prominent salt water and gas bearing formation.

The thickness of the Nacatoch sand, recognized as a lithologic unit, ranges from 50 to 150 feet and averages 125 feet. As described by the driller it consists of "gas rock," which in some logs is divided into a number of units, as in the following section:

Section of Nacatoch sand in a well in De Soto Parish, La.

	Feet.
Gas rock	10
Packed sand	13
Hard gas rock	12
Packed sand	10
Gas rock	65
Sandy gumbo	25

The lowest unit in the above section may not properly belong to the Nacatoch sand, although a part of that formation is sometimes

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[1] Matson, G. C., op. cit., pp. 17–19. Harris, G. D., op. cit., p. 125.

[2] Matson, G. C., op. cit., pp: 20–23. Harris, G. D., op. cit., pp. 123–124.

described as sandy shale. The recognition of hard and soft layers in the sand is common. There seem to be slight regional differences in the thickness or character of the formation as recorded in the well logs; many of the greatest differences shown are in neighboring wells, and these are attributed to inaccuracies of recording the character and thickness of the beds. The Nacatoch is therefore remarkably persistent and uniform.

This sand is an important gas-bearing formation, as might be inferred from its character as described above and its position between "impervious" beds. In the Caddo field this formation contains heavy oil as well as gas, but in the De Soto-Red River field it has furnished nothing but gas.

ARKADELPHIA CLAY.

Above the Nacatoch sand lie several hundred feet of clay and shale that are described by the well drillers as shale and gumbo. The lower portion of these beds belongs to the Arkadelphia clay,[1] but in the well logs this formation can not be separated from the overlying formation, of Eocene age. A small amount of sand occurs in this formation just above the Nacatoch sand. The Arkadelphia clay forms an impervious cap for the Nacatoch sand and prevents the escape of gas from it.

TERTIARY SYSTEM.

EOCENE SERIES.

MIDWAY FORMATION.

The first definitely recognizable formation in the wells of the De Soto-Red River field is the Nacatoch sand, which is reached at a depth of 700 to 900 or even 1,000 feet, the depth depending on the local structure. In penetrating to this sand the drill passes through part of the Wilcox and all of the Midway and Arkadelphia formations. It is not possible to distinguish these formations in the well records, because of the close similarity of the materials composing them. This is especially true of the Midway and Arkadelphia. In the absence of definite information the approximate base of the Wilcox may be considered to be at the base of sandy beds and layers of sandstone or concretions. On this arbitrary assumption the Midway and Arkadelphia are composed of about 500 to 600 feet of what the driller calls shale and gumbo and in some places boulders. How much of this thickness belongs to the two formations respectively can not be stated.

The Midway formation contains in southern Arkansas, according to Harris,[2] beds of hard light-gray limestone alternating with beds of light-yellow sand. Deussen[1] describes this formation in Texas as composed of a series of clays and limestones of marine origin containing in the lower part micaceous clays and clayey sands and having a thickness of 250 to 500 feet. In the Caddo field[2] the Midway is known from well logs to consist predominantly of clay, thin layers of glauconite and sand, and thin beds of rock which are probably in part sandstone and in part limestone, with a total thickness of 200 to 300 feet. To judge from the logs of the wells in the De Soto-Red River field the Midway in this field is composed of clay with thin layers of limestone.

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[1] Matson, G. C., op. cit., pp. 25–26. Harris, G. D., op. cit., p. 122.

[2] Harris, G. D., The Tertiary geology of southern Arkansas: Arkansas Geol. Survey Ann. Rept. for 1892, vol. 2, pp. 8, 22–35.

WILCOX FORMATION.

The Wilcox formation underlies the entire field and is exposed in more or less weathered form over more than half of it. In general the formation crops out in the hilly area and is concealed in the lowlands along the main streams and their tributaries. It is composed of alternating beds of lignitic sands and clays, together with ferruginous sandstone, calcareous sandstone concretions, and lignite. As exposed in this district the formation may be divided into two members—a clayey member below and a sandy member above.

The lower member consists largely of clay interbedded with thin lenticular layers of sand. In a fresh condition it consists of gray sandy laminated clay containing more or less comminuted plant remains and bluish-gray or drab hackly clay. On weathering the sand does not appear to be so abundant, and the material develops into a deep-red plastic clay, as exposed in and around Naborton. It contains calcareous concretions, and in its upper part ferruginous sandstone layers with plant impressions.

The sandy member is well exposed near Shreveport. It is composed of extensive lenticular beds of sand and subordinate beds of clay. Lignite, ferruginous sandstone and limonite pebbles are very abundant, and in some places clay pebbles and clay boulders. Ferruginous sandstone with leaf and other plant impressions is more plentiful in the lower part than in the upper part of this member. Limonite pebbles are also more numerous in the lower part, the iron being derived from the leaching of the ferruginous sands. These pebbles are formed most abundantly at the base of a sand bed that overlies clay, which prevents the downward circulation of the water. Silicified wood is common in both members, especially in the upper part of the clayey member and the lower part of the sandy member.

The general character of the Wilcox formation is shown in the following composite section:

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[1] Deussen, Alexander, Geology and underground waters of the southeastern part of the Texas Coastal Plain: U. S. Geol. Survey Water-Supply Paper 335, p. 31, 1914.

[2] Matson, G. C., op. cit., p. 26.

Composite section of Wilcox formation near Naborton, De Soto Parish, La.

	Feet.
Section 1 mile southwest of Zion Hill.	
Sand, of medium grain, orange-colored or yellow to gray	22
Sand, of medium grain, pure, orange-colored	17
Sand, same as below, with small pebbles of light-gray shale	13
Sand, of medium grain, pure, orange-colored to yellow	5
Lignite and bone	1
Sand	10
Clay, red	2
Sand	5
Shale, gray, arenaceous, weathering to red clay	7
Sandstone, concretionary; forms prominent, hard layers	1
Arenaceous shale or laminated sandy clay; weathers to deep-red fine sandy sticky clay	20
Concretionary layer, calcareous, sandy	1
Shale, arenaceous, grading upward into clay, carbonaceous clay, and laminated sandy clay, containing fossil leaves on top	24
Section 1 mile southeast of Naborton.	
Sandstone, hard, ferruginous, with fossil leaves; two collections, obtained in the SW. ¼ sec. 14	1
Clay, stiff, red, granular	25
Lignite and carbonaceous shale	2
Shales, arenaceous, weathering to red clay	10
Shales, gray, arenaceous, some with carbonaceous layers in lower part	13
Sand, yellow, hard, of medium grain	8
Sandstone, hard, ferruginous	2
Arenaceous shale or laminated gray sandy clay, with large concretions; carbonaceous in lower part	15
Shale	2
Sandstone, hard, ferruginous	2½
Sandstone, soft, grading into arenaceous shale below	9½
Shale, dark gray, with sandy layers	6
Shale, gray, arenaceous	2
Sandstone and shale; ferruginous pebbles and concretions	5
Sandstone, yellow, of medium grain, soft	3
Shale, gray, sandy, fine grained	6
From the log of a well near Naborton.	
Gumbo	15
Rock	3
Sand and boulders	4
Gumbo	7
Shale and rocks	123
Shale, gumbo, and rock	259
Gumbo and boulders	45
Base of Wilcox formation (?).	
	696

The lenticular character of the different beds of this formation may be recognized from a comparison of the logs of neighboring wells. Although there is always a close similarity in the nature of the materials found, the several beds do not show the same intervals or the same arrangement in wells only a fraction of a mile apart; sandstones and coal beds in one well can not be correlated definitely with similar beds in another.

The thickness of the Wilcox formation as penetrated by the drill in this field ranges from 300 to 500 feet, depending on the local structure, but farther south the thickness may amount to 800 or 1,000 feet. The formation is of no commercial importance in this district, and, although it contains a small amount of gas farther south, attempts to develop the gas have been unsuccessful. In this field the lower part of the Wilcox contains no thick beds of sand, and it is unlikely that either oil or gas will be obtained from it in commercial quantities.

QUATERNARY SYSTEM.

The early part of the Pleistocene time was a period of erosion, during which the major topographic features of the present day were beginning to form.[1] This period of erosion culminated when the general altitude of the region was probably slightly lower than it is now and the stream bottoms were relatively shallower. A gradual subsidence in later Pleistocene time made the streams more sluggish and therefore incapable of carrying as great a load as formerly; for this reason they began to fill the valleys and to build up the bottom lands. This condition continued until broad flood plains were formed on the large streams at altitudes of 190 to 210 feet. The relative position of the land and sea appears to have remained stationary for a considerable length of time, for this plain was extensively developed as a broad terrace covered by a thin veneer of fine sands and clay. In this particular area over part of this plain the Wilcox occurs at the surface with little or no covering of terrace deposits.

Late Quaternary or Recent time has been a period of erosion in this area; the streams have been sinking their beds into the plain previously formed. The overloading of the streams with silt and the formation of rafts which blocked the courses of the streams complicated their history; lakes, cut-offs, and minor terraces were thus formed, and these conditions have existed until the present time.

GENERALIZED SECTION.

Plates IX and X show the succession of strata as they are encountered in the wells of this field and are described by the driller. It will be noticed that there is a marked similarity, notwithstanding some more or less important differences, in these various well records. The greatest differences are probably due to errors in keeping the records and to misuse of the descriptive terms; thus the limestone of one driller may be the sandstone of another.

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[1] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, pp. 46–55, 1906.

Between the surface and the top of the gas sand there are from 725 to 975 feet of strata, the thickness depending on the altitude of the surface and the local structure; the average is slightly more than 800 feet. Of this material the upper 300 feet is commonly described as shale, sand, and gumbo, and the lower 500 feet as shale and gumbo with a little sand. The gas sand has a thickness of 50 to 150 feet, averaging 124. The thickness of the chalk ranges according to different records from 450 to 650 feet and averages 565 feet. It is encountered at an average depth of about 940 feet. Between the base of the chalk and the oil sand there are about 970 feet of strata. Of this material the upper 400 feet is composed largely of sand with smaller quantities of gumbo and shale; the lower 570 feet is composed of shale, gumbo, and limestone, with minor amounts of sand, except near the bottom. Between the oil sand and the deep gas sand there are 150 to 200 feet of shale, gumbo, and sand.

Contours on the top of the gas sand or the top of the chalk make the oil sand appear about 25 feet lower in the Red River district than in the De Soto district, and thus either the thickness of the interval between the oil sand and the top of the gas sand or the chalk is 25 feet less in the east end of the field, or else the oil sand occurs there 25 feet higher stratigraphically. As this change appears to be gradual from the western to the eastern part of the field it is attributed to a slight thinning of the strata in that direction.

COMPARISON OF DE SOTO-RED RIVER AND CADDO SECTIONS.

The well logs shown on Plates IX and X are arranged in their geographic position and represent the strata encountered in a series of borings extending from the Caddo field to the De Soto-Red River field. The upper part of the section down to the base of the gas sand is very similar throughout this area, but below that horizon there are some marked differences.

In the Caddo field about 250 feet of shale and gumbo with some chalky layers immediately underlie the Nacatoch sand and overlie the thick chalk beds. To the south the sequence is somewhat different, and in De Soto Parish the sand rests in general directly upon the chalk or is separated from it by not more than 50 feet of shale, which increases in thickness to about 100 feet in Red River Parish. The thickness of the material described as chalk by the driller is much greater in the De Soto-Red River field, and in four places out of five the chalk rests directly on sand; in the Caddo field, however, 150 to 200 feet of gumbo and shale intervene between the chalk and the sand. On the assumption that these sands, including the Blossom sand member in the Caddo field, are of the same age, the relation of the strata in the two fields appears to be normal, for the more southern field is farther away from the source of the sediments and would be expected to contain deposits formed in clearer water, such as limestone and chalk.

Whether this correlation is correct or whether the shale and gumbo above the Blossom sand in the Caddo field are the equivalent of part of the sands and shales in the De Soto-Red River field can not be definitely stated. In either case this portion of the section is more sandy in the southern field, and part of the 400 feet of dominantly sandy deposits here must represent the well-defined Blossom sand of the northern field, which has a thickness of 50 to 200 feet.

The thickness of the strata between the Nacatoch gas sand and the oil sand is 300 to 350 feet greater in this field than in the Caddo field, and the difference is explained by the increased thickness of sand mentioned above, the greater thickness of shale, and the presence of one or two moderately thick limestone beds. This difference in interval between the sands in the two fields suggests that they may not represent the same stratigraphic horizon and that the deep oil sand in the Caddo field may be higher and geologically younger than the deep oil sand and deep gas sand of the De Soto-Red River field. Most of the deep wells show a limestone bed ranging in thickness from 20 to over 100 feet that is stratigraphically below the oil sand in the Caddo field and above the oil and deep gas sands in the De Soto-Red River field. Some of the logs of the wells that lie between the two fields have been examined to determine whether they show this limestone. Few of the wells in the Caddo field reach the limestone, because most of them are finished at the oil sand, which lies 100 feet or more above it. But some of the wells drilled on the outskirts of the field that failed to obtain oil in the deep sand were continued to greater depths and encountered the limestone. Among these are Peak No. 1, in sec. 23, T. 22 N., R. 15 W.; the Douglass & Glassell No. 1, in sec. 30, T. 20 N., R. 14 W.; and the well of the Clover Leaf Oil Co., on the north side of Caddo Lake, about 1 mile west of the boundary between Louisiana and Texas. Among the wells between the two fields that encountered the limestone are the Allen No. 1, in sec. 11, T. 18 N., R. 11 W.; Page No. 1, in sec. 25, T. 18 N., R. 16 W.; Scott No. 1, in sec. 11, T. 18 N., R. 13 W.; McCutcheon No. 1, in sec. 3, T. 17 N., R. 14 W.: Youree No. 2, in sec. 18, T. 17 N., R. 13 W.; Cooper No. 2, in sec. 14, T. 17 N., R. 14 W.; and the well at Grand Cane, near the middle of T. 13 N., R. 14 W. This limestone is recorded in most of the logs of wells that have been drilled in the De Soto-Red River field, and although it is not recorded in the others or in some of the logs of the wells in the area between this field and the Caddo field, its apparent absence may be due to the fact that it has been described by other terms. Most of the logs that show no limestone record shale and boulders at the horizon where the limestone should be found, and the mistake would be very natural, because the limestone is hard and is usually ground to a very fine powder that may appear dark when mixed with the mud-laden fluid used in drilling.

Through the kindness of Mr. William C. Ribb, of the Producers Oil Co., the Geological Survey was supplied with some collections of fossils that came from the deep oil and gas sands in the De Soto-Red River field. These specimens were submitted to L. W. Stephenson, of the Survey, who reports as follows:

> Producers Oil Co. Sample C 10, depth 2,430 feet:
>
> Corbula aff. C. carolinensis Conrad.
> A gastropod (not identifiable).
>
> This type of Corbula ranges throughout the zone of *Exogyra ponderosa* Roemer in the Chattahoochee region. In terms of the section in the vicinity of Austin, Tex., the age would be that of the Austin chalk or of the Taylor marl. In terms of the section in northeastern Texas and southwestern Arkansas it probably corresponds in age to some part of the Brownstown marl or of the Annona chalk. It is probably older than the Marlbrook marl, with the possible exception of its basal beds.
>
> Producers Oil Co. Sample C 14, depth 2,870 feet:
>
> Ostrea lugubris Conrad.
> Volutoderma sp. (probably a new species).
> Prionotropis hyatti Stanton?
> Prionotropis sp.
> Callianassa sp. (a crayfish, identified by Miss M. J. Rathbun).
>
> Mr. Stanton has assisted me in identifying and correlating this lot. *Prionotropis hyatti* Stanton was found by him in the upper part of the Benton (*Pugnellus* sandstone) of the western interior. Young specimens belonging to this genus occur in the Eagle Ford shale in northeastern Texas. The *Volutoderma* is similar to though not identical with any one of the species of this genus found associated with *Prionotropis hyatti* Stanton in the western interior. *Ostrea lugubris* Conrad is a characteristic species of the upper part of the Eagle Ford shale of northeastern Texas and occurs also in association with *Prionotropis hyatti* Stanton and with the species of *Volutoderma* in the western interior.
>
> We regard this lot as indicating a stratigraphic position corresponding to the upper part of the Eagle Ford formation of Texas and to the upper part of the Benton formation of the western interior.

Mr. Stephenson has also examined a specimen from the Producers Oil Co.'s Wemple "B" 1 well, in sec. 22, T. 12 N., R. 11 W., from a depth below 2,626 feet.

> *Prionocyclus* sp. (probably an undescribed species). The genus has been reported only from the Colorado group of the western interior. At localities where the stratigraphic position is definitely known it is below the Niobrara limestone. The evidence indicates that, in terms of the Gulf Cretaceous nomenclature, the specimen came from either the Austin chalk or the Eagle Ford shale, and I am inclined to the opinion that it is from the latter.

These fossils furnish satisfactory evidence, provided there is no mistake as to the depths from which they came, that the oil sand and the deep gas sand in the De Soto-Red River field are of Eagle Ford age, and from the evidence that is summarized on page 114 it is apparent that these sands are stratigraphically lower than the deep oil sand of the Caddo field. Hence, if they are of Eagle Ford age, the sand of the Caddo field must be at least as young as the Eagle Ford.

STRUCTURE.

CONTOUR MAP.

Most sedimentary rocks, such as sandstone, shale, and limestone, are deposited from water in approximately horizontal, parallel beds. Such beds or strata may remain in that position or they may be bent and broken. Bending produces folds, and breaking and slipping of the strata produce faults. The upward folds are known as anticlines and the downward folds as synclines. The economic importance of folds is due to the fact that oil and gas are commonly associated with anticlines. The attitude or position of the rock beds with reference to a horizontal plane is called structure.

Structure may be represented diagrammatically, the arrangement and inclination, or dip, of the strata being shown along a particular line; or by contour lines, as on Plate VIII (in pocket), where the shape and areal extent of the folds are represented by lines that connect points of equal altitude on one particular bed, called the key rock. The mode of interpreting a structure-contour map may be best understood by a consideration of the method by which it may be prepared.

It is necessary to select as a key rock some bed that can be recognized over the area to be mapped. In the preparation of the accompanying map the top of the shallow gas sand (Nacatoch sand) was selected. The depth of the top of the gas sand was determined from the logs of the wells. The altitude of the wells above sea level was determined from level lines run to the wells, and by subtracting the altitude of the well from the depth to the top of the gas sand, the depth of this key rock below sea level was determined for each well. With these data it was possible to draw contour lines connecting points where the oil sand has approximately the same depth below sea level. As these lines represent depths below sea level the direction from one contour line to the adjacent one marked with a larger number indicates the direction of the dip; the rate of dip is greatest in the area for which the contour lines are closest together and least in the area for which they are farthest apart. The beds dip in opposite directions away from the crest or axis of an anticline and toward the axis of a syncline. By representing the direction and rate of dip the contour lines outline the shape and areal extent of anticlines and synclines.

If the beds above the gas sand were removed and its surface exposed to view, the anticlines or upward folds would represent hills and the synclines or downward folds would represent valleys. In following the path indicated by one of these contour lines around a hill or a valley the traveler would remain always at the same altitude.

One of the commonest mistakes, however, is to assume that the upfolds and downfolds of the formations underground are the same as the hills and valleys of the surface. Round hills, for example, are often mistaken for domes, and ridges are often thought to be long anticlines. Because of mistakes of this character, it should be borne in mind that the visible hills and valleys may bear no relation to the structure of the formations beneath the surface; in fact, the relation may be exactly the reverse of what might naturally be expected, the anticlines lying beneath valleys instead of beneath hills.

GENERAL STRUCTURE.

The De Soto-Red River oil field is on the southern part of the Sabine uplift, which is outlined in part on the diagram (Pl. VII) by a line indicating the area over which the top of the Nacatoch sand is less than 1,000 feet below sea level. The contour lines on Plate VIII (in pocket) show the minor structural features in as great detail as was possible with the information available from well logs and examination of surface exposures. These lines represent the top of the Nacatoch sand (gas sand), and the figures accompanying them show the depth of the surface of this sand below sea level.

The folds as represented by these contour lines are very irregular in shape, but probably a great part of this irregularity is due to lack of sufficient information to represent the details of structure. The height of the principal folds is comparable with that of the highest part of the folds in the Caddo field.[1] The highest part of the Nacatoch sand in the Caddo field east of Mooringsport is, as shown by the contour lines, 550 feet below sea level, and the highest part of the folds in the De Soto-Red River field, as shown by contour lines on the same formation, is 525 feet below sea level.

The mapping of the structure on Plate VIII is not as detailed as that shown on the contour map of the Caddo field, because the wells in this field are fewer and not as evenly distributed over the area, and therefore there is less information to supply details of the structural features. Probably if sufficient data could be obtained more subordinate anticlines and synclines could be shown. The structural features as represented include a broad, irregular, dome-shaped fold—the Naborton dome—showing well-defined general dips away from its highest part. North of this dome-shaped area is a more definite anticlinal fold—the Smithport anticline—that follows the general direction of the Smithport road southwestward from a point near Bayou Pierre Lake. The northern and western margins of the central dome are made irregular by a number of small anticlines that project from it. South of the central area is the Bice anticline, but the amount of information available does not permit accurate contouring of this fold. Northeast of the central area, in Red River Parish, there are low anticlines and a broad structural terrace called the Crichton terrace. The most productive anticline in this part of the field is the Gusher Bend anticline. The structural terrace has not been contoured along its southern extension and is represented as terminating against a fault that extends from the south-central part of the field eastward to a small oil pool in the hilly region east of Red River.

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[1] Matson, G. C., op. cit., pl. 7.

The depth of the Nacatoch sand below sea level ranges from 525 feet on the crest of the Naborton dome to 875 feet in the lowest area contoured. The rate of dip in the different parts of the field varies widely, from a few feet to 200 feet or more to the mile.

FORM AND AGE OF FOLDS.

In considering the folds in the Caddo oil field[1] it was noted that there had been folding in two different directions, one set of folds extending in a northeasterly direction and another, consisting of a broad axial fold with minor folds parallel to it, in a northwesterly direction, at nearly right angles to the northeasterly folds. These sets of folds are probably represented in a general way on the entire surface of the Sabine uplift, though their shapes and sizes, as well as their altitudes, are variable. The northwesterly arch that forms the axis of the Sabine uplift probably extends in a more or less direct course southward beyond the De Soto-Red River field. Its extension toward the northwest has not been traced, and its course may not be as straight in that direction as farther south, though it probably connects with the axis in the Caddo field. From this axis the minor folds that cross it pitch both to the northeast and southwest. That these two sets of folds were produced by pressure exerted approximately parallel to the bedding is inferred from the fact that where the folds can be examined at the surface they consist of a series of parallel anticlines and synclines such as would be formed if the beds were subjected to lateral pressure. The formation of the two sets of folds was not simultaneous, as is well illustrated in the Caddo field, in which the northeasterly folds are bent where they are crossed by the northwesterly folds. Apparently the northeasterly folds are the older, and were distorted by the later folding. The exact time of folding can not be determined from the study of one small area. Both sets of folds affected beds of Wilcox age in the De Soto-Red River field, and must, therefore, have been formed in post-Wilcox time; the general folding that produced the Sabine uplift involved the youngest Eocene beds farther south, and it is therefore safe to conclude that the folding is, in part at least, post-Eocene.

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[1] Matson, G. C., op. cit., pp. 35–37.

In preparing the structural map of the De Soto-Red River field it was found that the axes of folds drawn by means of different formations as key rocks did not coincide, and this characteristic is also shown on the structural map of the Caddo field. It is suggested that the folding began during the deposition of the Upper Cretaceous formations, and that this may account for a certain erratic lack of parallelism of the formations in the Upper Cretaceous and also for some differences in position of the axes of folds contoured on different formations, though some of these differences may be explained in other ways.

LOCAL STRUCTURAL FEATURES.

NABORTON DOME.

The broad, flat-topped dome that lies south of the town of Naborton is elongated in a northeasterly direction, its major axis extending across the major axis of the Sabine uplift. The highest part is in secs. 5 and 7, T. 12 N., R. 11 W. There is a gentle dip away from this apex which increases gradually and becomes much steeper at distances of a few miles. The northern flank of the Naborton dome is crossed by a shallow syncline that separates the apex from the oil-producing areas near Naborton, and the western margin is made irregular by a number of small pitching anticlines and synclines. The eastern margin is much more regular than the western and extends down to the area where the dip is low, west of the oil pools in Red River Parish. The south edge of the Naborton dome is formed by the Gusher Bend fault, which carries all the formations abruptly downward toward the south.

SMITHPORT ANTICLINE.

A long, narrow anticline that extends from a point near the Sample wells of the Producers Oil Co., at the west edge of Bayou Pierre Lake, southwestward across secs. 22, 28, and 32, T. 13 N., R. 12 W., is here called the Smithport anticline. This fold is much lower than the Naborton dome, and from the meager information available it apparently has gentle dips except near the east end, where it plunges steeply toward the northeast. It is separated from the Naborton dome by a shallow syncline that deepens both toward the northeast and the southwest, the higher part being along the line of the major axis of the Sabine uplift.

BICE ANTICLINE.

Some distance south of the Naborton dome, in secs. 4, 5, and 6, T. 11 N., R. 11 W., and secs. 34, T. 12 N., R. 11 W., there is a long, narrow fold called the Bice anticline. The detailed information about this anticline is scanty, but it is apparently low, having much gentler dips than the higher folds to the north. Its axis is curved, possibly as a result of the same forces that produced the Gusher Bend fault.

CRICHTON TERRACE.

The Crichton terrace, in secs. 19, 20, and 30, T. 13 N., R. 10 W., occupies an area where the dip of the formations is very low, and although the structure immediately east of it could not be contoured, the arrangement of the surface formations indicates that the dip increases toward the northeast. It is also possible that this terrace is separated by a broad, shallow syncline from the area of higher folding southwest of it, but there is no information concerning this area aside from that supplied by a few scattered dry holes, and these data are not sufficient to show the details of the structure. The Crichton terrace is crossed by a number of shallow synclines and anticlines that pitch toward the northeast.

GUSHER BEND ANTICLINE.

Associated with the Crichton terrace is a low, broad anticline that trends slightly east of north. This anticline is in secs. 24, 25, and 36, T. 13 N., R. 11 W., at the bend of the river where large yields were obtained in many wells, and is called the Gusher Bend anticline.

GUSHER BEND FAULT.

The southern margin of the Crichton terrace and the Gusher Bend anticline, as outlined on the map, is formed by the Gusher Bend fault, a break in the strata which near Red River has carried the formations downward on the south side of the fault between 200 and 225 feet below their position on the north side. This fault is marked on the eastern wall of the Red River valley by a nearly vertical contact between the clays in the lower part of the Wilcox formation and the sands forming the upper part of the Wilcox. The best information concerning the amount of movement along this fault plane was obtained on the Armistead lease of the Gulf Refining Co., where it was from 200 to 225 feet, and the amount of movement is supposed to diminish westward to the point where the fault terminates. Toward the east this fault may extend to a small pool that has been developed on the property of the Globe Lumber Co. and beyond.

OTHER FAULTS.

No attempt has been made to locate all the small faults in the De Soto-Red River field, though it is believed that there are several minor ones that extend in the same general direction as the Gusher Bend fault. Probably none of these faults are of very great magnitude, and their effect on production is likely to be local. Among the places where such faults have been suspected is a locality on the Christine lease of the Producers Oil Co., where a producing well was obtained in the chalk rock, and another on the lease of the Wilson-Broach Oil Co. in the Naborton pool, where a showing of oil was obtained in the chalk.

OIL AND GAS.

OIL AND GAS BEARING FORMATIONS.

GEOLOGIC POSITION.

The producing oil and gas bearing sands of northwest Louisiana are found in the Gulf series or Upper Cretaceous, which includes in this region the following formations, arranged in order of superposition:

Formations of Gulf series (Upper Cretaceous) in De Soto River oil and gas field, La.

Formation.	Character.	Oil or gas.	Range in depth.
Arkadelphia clay.	Stiff, gummy clay, with some sandy layers in lower part.		
Nacatoch sand.	Sand, with some layers of clay and hard sandstone.	Prominent gas sand.	Top at 725-975 feet.
Marlbrook marl.	Shale or marl above; white chalk below.	Some oil, supposedly derived from lower formations through faults.	Top at 850-1,050 feet.
Annona chalk.	Chalk.		
Brownstown marl.	Probably marl and chalk above; shale and sandy shale, with some sand, below.		Showings of oil and gas below base of chalk.
Eagle Ford shale.	Shales, sands, and probably limestone beds.	Principal oil sand of field; also deep gas sand.[a]	Oil sand at 2,450-2,550 feet; deep gas sand at 2,650-2,750 feet.
Woodbine sand.	Not definitely recognized in this field.		

[a] Exact correlation uncertain; may be older than indicated. (See pp. 115-116.)

All the sands of these formations appear to be saturated and usually yield a flow of salt water where oil and gas are absent.

NACATOCH SAND.

Because of its porous character over wide areas, the Nacatoch sand is particularly suitable as a reservoir for the collection of oil and gas and for their accumulation in areas of favorable structure. It is composed of 50 to 150 feet of sand of variable porosity, with a number of irregular indurated layers. This sand is the shallowest productive formation in the field and occurs at a depth of 725 to 975 feet, the depth depending on local structure and the altitude of the surface. It has been tested at a number of widely separated places in the field and has yielded, so far, large quantities of gas but little or no oil. The wells in this sand have capacities reaching 15,000,000 cubic feet of gas a day and rock pressures of 300 to 350 pounds to the square inch.

CHALK.

Oil is found sporadically in the chalk, and at least one well has been finished in it. The oil may occur in a porous layer of chalk or sand, but it is much more probably contained in cracks and crevices, having migrated upward along a fault plane.

OIL SAND.

The principal oil-bearing formation of this field is approximately 1,660 feet below the top of the Nacatoch sand, and, as stated on pages 115–116, its exact age is not known. The productive sands are found below one or more beds of limestone which seem to be persistent but which are variously described as limestone, chalk, shale, boulders, etc. The sands are relatively thin and lenticular and are interbedded with shale and some hard layers. They do not occur at a very definite horizon but extend through an interval of 50 or 100 feet. The greater variability in the character of these sands, as compared with that of the Nacatoch sand, makes them less regular in production, especially in De Soto Parish. In Red River Parish the sand appears to be more persistent and consequently more uniformly productive.

Over the greater part of the productive area wells drilled in this sand have a strong initial flow ranging from less than 100 to 6,000 or 8,000 barrels in 24 hours. Wells producing 1,000 barrels or more are common, especially in the east end of the field. (See figs. 19, 20.) The wells decline gradually as the pressure is relieved and finally cease to flow; they are then pumped until exhausted.

These sands are also a minor source of gas, and some wells of good volume and pressure have been completed in them. The wells have a maximum volume of 15,000,000 cubic feet and rock pressures of 700 to 1,000 pounds to the square inch.

DEEP GAS SAND.

Between the oil-bearing sands just described and the deep gas sand there is an interval of 150 to 200 feet, which is occupied by shale, hard layers of sandstone or shaly limestone, and thin beds of sand. The amount of sand increases in the lower part. The gas in the deep sand occurs in well-defined beds of considerable thickness, which are probably of greater persistence than the higher sands, because these lower beds are more uniformly productive. Some wells that are unproductive in the oil sand have been developed as "gassers" of considerable volume in this deep sand.

The capacity of the wells in the deep gas sand reaches 35,000,000 cubic feet or more, and the rock pressure ranges from 1,000 to more 1,200 pounds to the square inch.

ORIGIN.

A discussion of the theories that have been advanced to explain the formation of oil and gas is beyond the scope of this paper. In seeking for a source for these materials in the De Soto-Red River field it was found that the shales associated with the sands and in some places the sands themselves contain considerable organic matter which was apparently derived chiefly from vegetation, and it is believed that the oil and gas were formed from this organic matter by slow chemical changes, which may have been facilitated by moderately high temperature and the pressure caused by the load of sediments that overlie them, and by the thrusts to which they have been subjected. The gas from the Nacatoch sand is chiefly methane, and is almost identical in composition with some of the gas formed from decaying vegetable matter in present-day swamps where there is enough water to exclude the air from the decomposing vegetation.

The gas in the deeper sands has a different composition, but this may be explained by the fact that it was probably formed at greater depths, where the temperature was higher and the pressure greater. The theory that oil and the higher hydrocarbons in the deep gases may have been derived from bituminous shales is supported by results of recent examination of oil shales in the Western States.[1] There is no doubt that clays and shales similar to these oil shales have a comparatively wide distribution, because oil can be distilled from most carbonaceous shales. Although the temperatures used in distilling the oil shales are higher than temperatures ordinarily found at the depths of the oil and gas sands, the distillation might be accomplished during long periods of time at lower temperatures.

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[1] Woodruff, E. G., and Day, D. T., Oil shale of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 581, pp. 1–21, 1915. Winchester, D. E., Oil shale in northwestern Colorado and adjacent areas: U. S. Geol. Survey Bull. 641, pp. 139–198, 1916 (Bull. 641–F).

RELATION TO STRUCTURE.

GENERAL RELATIONS.

The early investigations in oil fields revealed the fact that the occurrence of oil and gas is related to the structure of the oil sands and associated formations. In some of the older fields the relations to structure were very clear, the oil and gas having accumulated in anticlines, in which gas occupied the higher parts of the folds and beneath that in regular succession came oil and salt water. In some places where the gas was absent the oil occupied the top of the fold. It was noted that these substances were arranged in the anticlines in the order of their specific gravity, the lightest substance, gas, being at the top, and the heaviest, salt water, being the lowest. It was supposed that these substances had originally been mixed and that they had separated and taken up their relative positions under the influence of gravity. This explanation was satisfactory for a great many oil and gas fields and for a long time it remained unmodified.

The condition of the water, whether stationary (hydrostatic) or moving (hydraulic), was not discussed in presenting the earlier explanations of the relation of oil and gas to structure. The important points were that these substances had originally been mixed with the salt water and had been separated out. Later investigations threw some doubt on the adequacy of the anticlinal hypothesis of separation under the influence of specific gravity alone and experiments[1] were undertaken to determine whether such separation would take place. In investigations lasting several months oil did not rise through sands saturated with salt water, and although the period covered by the investigators was short the results suggested the inadequacy of the older hypothesis. A newer and modified form of this hypothesis is that the separation took place while the fluids were circulating through the porous beds, the accumulation being facilitated by the movement of these fluids and the arrangement being determined by the gravity of the substances. It might be urged against this explanation that there is probably very little circulation of water in deeply buried sands and that the character of the water associated with the oil and gas indicates that no great amount of circulation has taken place. However, it is probable that there are very few sands in which there is no movement of water and it is not necessary that this movement be sufficiently great to permit the incursion of fresh water into the field in order to cause the accumulation of the oil and gas. Probably the major portion of the circulation is everywhere under the influence of gravity and its direction is away from the place where the porous formation is at the surface. Circulation may have taken place in folded beds at the time of folding, water having been squeezed out of the porous beds as the result of pressure and consequent decrease in volume of pore space in the formation. Accumulation as the result of hydraulic pressure will take place where there are anticlines to trap the lighter fluids or where there are local barriers to the migration of the fluids. These local barriers may be either lenticular beds of fine sand, indurated sandstone, or lenses of clay. It is probable that in many places accumulation is the result of the combined effects of folds and relatively impervious barriers in the oil sands.

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[1] Munn, M. J., Reconnaissance of the Grandfield district, Okla.: U. S. Geol. Survey Bull. 547, pp. 78, 79, 1914.

In the examination of the western oil shales[1] it was found that a small amount of the oil existed as such in the shale before distillation. If it is assumed that oil is formed in the shales and sands, as has been outlined in discussing the origin, the principal problem involved is to explain its accumulation in porous sands under the influence of structure and variations in the texture of the sands. Probably the first process is a slow interchange in position of water and oil, the oil moving into the more porous beds and the water into those of finer texture. This interchange would be facilitated by the slow earth movements that are probably constantly in progress and would be hastened by the processes of deformation that produce the folds. The final process would be migration of the oil under hydraulic pressure and accumulation in the large productive pools under the influence of the water circulation and gravity.

RELATIONS IN THE DE SOTO-RED RIVER FIELD.

The gas and oil in the De Soto-Red River field were probably accumulated under hydraulic pressure. This hypothesis is supported by the relations of these substances to the structure and by the occurrence of the oil in very productive pools of small area. The amount of oil in these pools is too great to be satisfactorily explained by assuming a local source on the flanks of the gentle folds that exist in this region.

NACATOCH SAND.

The Nacatoch sand in the De Soto-Red River field has furnished considerable gas but no oil, though drilling has not been extended around the gas-producing area, and therefore it is not safe to say that oil will not be found in this sand. Because of its wide distribution and notable porosity, the Nacatoch sand presents ideal conditions for the accumulation of oil and gas under the influence of gravity; in other words, it favors accumulation according to the anticlinal theory. However, it is unlikely that the salt water that is abundant in the sand below the level where gas occurs has been stationary during the gas accumulation. This sand furnishes gas at many places in northwestern Louisiana, and, so far as has been noted, the gas occurs invariably in high parts of the folds. In the Caddo field the lower limits of the gas-bearing portion of the sand follow very closely the course of one of the structure contours, and although the volume of gas in the De Soto-Red River field is not as great as in the Caddo field, it is probable that the lower margin lies at a nearly uniform level in this field also, though somewhat higher than in the Caddo field. If any oil is found in this sand it will be around the margins of the gas-producing area.

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[1] Woodruff, E. G., and Day, D. T., op. cit., pp. 6-7.

CHALK.

Very few wells encountered any showings of oil in this chalk, and the only one that has proved an important producer is on the Christine lease of the Producers Oil Co., but wells in chalk rock are much more common in the Caddo field, and the distribution of the oil, as shown by the drilling of many wells in close proximity to large wells in this formation, indicates that the oil comes either from a porous bed of slight extent or from crevices. It is therefore suggested that the oil in the chalk may have been derived from the deeper sands by migration along fault planes. A showing of oil has been noted in the sands immediately below the chalk, but no oil has been produced from these sands, and it is impossible to say whether the oil in the chalk has accumulated from local sources or has migrated to its present position from some distant source.

OIL SAND.

The oil sand in the De Soto-Red River field does not present favorable conditions for accumulation in the higher parts of the folds, because the beds are more or less lenticular and the formation is thin. An examination of the relation of the oil pools to the structure shows that they occur considerably below the tops of the highest structural features, probably because of minor structural features and because the upward migration has been interrupted by barriers in the form of fine-grained sands or beds of shale. It is difficult to get reliable information concerning the thickness and character of the sands from the samples obtained in drilling by the rotary method, but many of the wells that are outside of the producing areas and between those areas and the high parts of the folds show considerable porous sand, and it is unlikely that the migration of the oil is prevented by continuous barriers of fine-grained sediments. The principal areas of production in this field are all in places where there is a flattening of the dip on the slopes of the major folds, and it is probable that the accumulation was influenced more by this flattening, which in the area containing the pools in Red River Parish forms a a well-defined structural terrace, than by increase in the fineness of the sand. There can be little doubt that the oil in the larger pools has been brought to its present position, in part at least, by movements of the water through the sand, and it will be observed that the producing areas lie where the circulation would be first impeded by the change in structure.

The producing areas near Naborton are on the north flank of the Naborton dome, above the bottom of the syncline that separates this dome from the Smithport anticline, in the locality where this syncline is rendered shallow by crossing the major axis of the Sabine uplift. The pools in Red River Parish are on the east edge of the Sabine uplift, and although little information is at hand about the dip to the northeast beyond the productive area, it is probably much steeper there than in the producing areas.

On page 107 it was noted that there is a resemblance between the formations penetrated in the lower parts of the wells in this field and those in southern Arkansas, and it is believed that this resemblance is to be explained by the facts that the drainage which brought these materials to their present position came from the northeast and that the sands are therefore continuous between this field and southern Arkansas. This circulation of the water from the northeast would favor the accumulation of oil on the northeast side of the folds, whereas circulation from the northwest, such as clearly occurred in the Caddo field, would favor accumulation on the northwest side of the folds and would present conditions that were unfavorable for large pools on the east side, where the most productive areas in the De Soto-Red River field are located.

DEEP GAS SAND.

The deep gas sand is productive more uniformly and over a wider area than either the oil sand or the shallow gas sand. Many wells that have been drilled to the oil sand without success have obtained gas in the deep gas sand. Moreover, the relation between the structure of the rocks and the accumulation of gas in this sand is closer than that between the structure and the accumulation of oil in the oil sand.

The wider distribution of the gas in this sand is shown by the occurrence of gas farther down the slopes of folds and on lower folds than in the higher sands, as is illustrated by the large gas wells on the Sample lease of the Producers Oil Co., in sec. 23, T. 13 N., R. 12 W., and by McCormick-Nabors well C–2 of the Gulf Refining Co., in sec. 28, T. 13 N., R. 11 W. It is necessary to conclude, therefore, that the ratio of the volume of the gas to the salt water in this sand is greater than that of the oil and gas to the salt water in the overlying sands. These facts and the general occurrence of gas in the deep sand in areas of favorable structure lead to the conclusion that this sand is more uniform in thickness and porosity than the oil sand above.

COMPOSITION.

OIL.

ANALYSES.

The analyses shown in the accompanying table were made of small samples from individual wells, and the results may not be characteristic of the oils of the different fields. The gravity of northwestern Louisiana oils, in degrees Baumé, is given by J. W. Smith[1] in a recent report, as follows: Caddo light, 38–45.5; Caddo heavy, 19–38; De Soto, 38–41.5; Red River, 40.5–42.5. The gravity of the different samples as shown in the tables differs only slightly from the figures given by Smith, though in comparing individual fields it will be noted that none of the samples from the Caddo field approach the maximum gravity for that field. It must be inferred, therefore, that these samples do not include a representative of the lightest oil of the Caddo field.

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[1] Louisiana Conservation Comm. Rept. from Apr. 1, 1914, to Apr. 1, 1916, p. 73.

Analyses of oil from the De Soto-Red River field and neighboring fields in Louisiana and Texas.

Formation and well.	Location.	Depth of sand (feet).	Total depth of well (feet).	Crude.			To 150° C.		150°-300° C.		Residuum.		Unsaturated hydrocarbons.		Asphalt (per cent).
				Cubic centimeters.	Gravity.		Cubic centimeters.	Specific gravity.	Cubic centimeters.	Specific gravity.	Cubic centimeters.	Specific gravity.	Crude (per cent).	150°-300° C. (per cent).	
					Specific.	Baumé.									
Chalk rock.															
De Soto Parish:															
Christine No. 16	Near Naborton, La		1,186	100	0.7973	45.6	27	0.7200	55.5	0.7990	17.5	0.9050	8.8	6	0.09
Caddo field:															
Leonard No. 1, Richardson Oil Co.	Near Oil City, La	1,460	1,473	100	.9138	23.2	1		40.5	.8800	58.5	.9300	23.2	10	2.95
Oil sand.															
De Soto Parish:															
Scales No. 1	Sec. 35, T. 13 N., R. 12 W	2,382		100	.8069	43.5	19	.7230	50	.7960	31	.8870	8.8	6	.0
Red River Parish:															
McClelland No. 6	Sec. 13, T. 13 N., R. 11 W	2,540	2,550	100	.8226	38.94	6		67	.7990	27	.8930	8.4	4	.09
Robinson No. 3	Sec. 25, T. 13 N., R. 11 W		2,535	100	.8154	41.7	11.5	.7400	64.5	.8000	25	.8890	8	1	
Marston No. 15	Sec. 13, T. 13 N., R. 11 W		2,554	100	.8202	40.7	12	.7510	70.5	.8075	17.5	.9390	6.4	4	.18
Globe Oil & Gas Co. No. 1	Sec. 16, T. 13 N., R. 10 W	2,614		100	.8299	38.7	4.5		68.5	.8000	27	.8910	9.6	5	.3
Caddo field:															
McCue Levee Board No. 2	Sec. 36, T. 21 N., R. 16 W	2,180–2,221	2,221	100	.8969	26.1	2.5		35	.8540	62.5	.9130	21.2	7	2.01
Allen No. 1	Sec. 18, T. 20 N., R. 15 W., near Oil City, La.		2,328	100	.8313	38.38	16	.7265	43	.8025	41	.8980	11.2	6	.45
Pelican field:															
Logan No. 6	Sec. 16, T. 10 N., R. 12 W			100	.8154	41.7	16.5	.7355	57.5	.8070	26	.8870	8	8	
Joiner No. 1	Sec. 28, T. 11 N., R. 12 W		2,970	100	.8107	42.7	13.5	.7200	56	.7980	30.5	.8820	6.4	1	
Nacatoch sand.															
Caddo field:															
Dawes No. 1[a]	Sec. 36, T. 22 N., R. 16 W		1,050	102.9	.9253	21.3			17.0	.8406	82.9	.9302			.22
Corsicana field (Powell pool):															
Wright No. 6	5 miles southeast of Corsicana, Tex	860			.9109	23.7	1		33	.8680	66	.9260	30	13	1.14
Corsicana sand.															
Corsicana field:															
Robbins Nos. 7 and 12	2 miles southeast of Corsicana, Tex		1,131 1,155		.8304	38.6	21	.7238	48	.8150	31	.9130	12.8	4	.83

[a] Harris, G. D., Oil and gas in Louisiana: U. S. Geol. Survey Bull. 429, p. 131, 1910.

In discussing the analyses it is assumed that the product up to 150° C. is gasoline, that between 150° and 300° C. is kerosene, and the remainder is residuum. In refining the amount of gasoline may be increased by distilling to a somewhat higher temperature, provided the requirements of the trade do not call for a high-gravity gasoline, and it is probable that in practice some of the oil that distills above 150° is included with the gasoline. This would result in a decrease in the amount of kerosene unless the oil is distilled at a higher temperature than 300° C. in producing the kerosene. With increased temperatures the gravity of the product is lower. It is important to know the percentages of unsaturated hydrocarbons, especially those of the kerosene, because thorough refining necessitates their removal, which adds to the cost of producing the kerosene and decreases the quantity.

OIL FROM CHALK ROCK.

Two samples were obtained from wells that procured oil in the chalk rock. One of these, from the Christine well, in De Soto Parish, has a specific gravity of 0.7973 (46.6° B.), which indicates that it is one of the very light oils of northwestern Louisiana and not a heavy oil such as is characteristic of the chalk rock. The sample from the Leonard well No. 1, in the Caddo field, is much more representative of the oil from the chalk rock than that from the Christine well. The percentage of unsaturated hydrocarbons in these two samples is very different, but there is a closer agreement in the percentage of unsaturated hydrocarbons in the kerosene. The two samples also differ notably in their percentages of asphalt.

OIL FROM OIL SAND.

The oil from the deep sand in De Soto Parish is represented by a single analysis, but the deep sand in Red River Parish is represented by three samples that show a small variation in the gravity and the content of lighter hydrocarbons and considerable variation in the percentages of kerosene and residuum. The percentages of unsaturated hydrocarbons in the crude samples from De Soto and Red River parishes were comparatively low, and those in the kerosene were too low to be important. None of these samples showed high percentages of asphalt.

In the Caddo field the deep sand is represented by two samples, one of which, from the McCue Levee Board well, was of exceptionally low gravity for deep-sand oil in this field, and its percentage of gasoline was correspondingly low. The gravity of the sample from the Allen well was only a fraction above the lowest gravity given by Smith for the light oils of this field, but this sample furnished a high percentage of gasoline. The yield of kerosene from these two samples was relatively low. The percentages of unsaturated hydrocarbons were apparently high for the deep-sand oils, and there was a wide variation in the asphalt.

Two samples from the deep sand in the Pelican field showed little variation in the gravity and in the amounts of light hydrocarbons. They averaged slightly higher in gravity and in the contents of gasoline than the samples from Red River Parish, but their kerosene yield was somewhat lower. The percentages of unsaturated hydrocarbons were relatively small and neither of these samples showed any asphalt.

OIL FROM SHALLOW SAND.

In northwestern Louisiana the only shallow sand that has furnished oil is the Nacatoch sand in the Caddo field, but in northeastern Texas two or three shallow sands have been productive. The relations of these sands to the Nacatoch sand in Louisiana have been determined, the one at Powell being of the same age as the Nacatoch sand, the one at Corsicana being older, and the one at Angus being doubtfully correlated with the Nacatoch sand. For purposes of comparison some analyses of samples from these shallow sands have been inserted in the table. The sample from the Nacatoch sand (Dawes well) is much heavier than most of the samples obtained from the deep sand in northwestern Louisiana, but only slightly heavier than the sample from the Leonard well, in the Caddo field. The Wright well, in the Powell field, furnished a sample that was a little lighter than the one from the Dawes well. The sample from the Corsicana field was a composite of the oil supplied by two wells. This oil was much lighter than that from the Powell field, and its gasoline yield exceeded that of any of the samples from northwestern Louisiana except the one from the Christine well. The amount of kerosene was somewhat lower than in the samples from De Soto and Red River parishes, but higher than in those from the deep sand of the Caddo field. The percentages of unsaturated hydrocarbons in the crude samples from the Corsicana field were relatively high, and those in the kerosene were high in one sample and low in the others. The asphalt in one sample, that from the Dawes well, was low.

GAS.

The analyses in the subjoined table show the composition of the gas obtained in a number of wells in northwestern Louisiana from different sands, and in one well in the Mexia-Groesbeck field, Texas, from the Nacatoch sand, the substantial equivalent of the shallow gas sand of northwestern Louisiana. The analysis of a sample obtained from the Mackey lease, near Corsicana, is also included, though the sand containing this gas is probably slightly older than the Nacatoch.

Analyses of gas from Louisiana and Texas.

[Made by Bureau of Mines; G. A. Burrell, analyst. Samples collected by O. B. Hopkins, except as otherwise stated.]

	1	2	3	4	5	6	7	8	9	10	11	12
Carbon dioxide (CO_2)	1.6	1.5	1.0	0.0	0.0	0.6	Tr.	1.7	1.2	0.2	0.9	0.3
Oxygen (O_2)	.3	2.0	.0	.1	.0	1.0	0.0	1.1	.0	.1	.0	.0
Methane (CH_4)	95.6	89.3	98.5	96.9	96.5	94.3	98.5	91.9	98.7	92.4	91.9	97.5
Ethane (C_2H_6)	......	......	......	......	......	......	......	......	......	3.4	6.2	.0
Nitrogen (N_2)	2.5	7.2	.5	3.0	3.5	4.1	1.5	5.3	.1	3.9	1.0	2.2
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Specific gravity:												
Determined	0.58	0.58	0.57	0.58	0.57	0.59	0.56	0.60	0.58	0.60	0.62	0.57
Calculated	......	.57	.57	.57	.57	.58	......	......	.57	.59	.60	......
Oil absorption (per cent)	10.6	4.6	......	......	10.0	10.0	......	......	11.2	......	11.8	......
Heating value (British thermal units per cubic foot at 0° C. and 760 millimeters pressure)	1,018	1,044	1,050	1,031	1,027	1,052	1,052	979	1,051	......	1,095	1,038

Nos. 1 to 7 from Nacatoch sand; No. 8 older sand in Corsicana field; Nos. 9 to 11 from oil sand; No. 12 from deep gas sand.

1. Well No. 28 of Arkansas Natural Gas Co., sec. 6, T. 21 N., R. 15 W., 2½ miles south of Vivian, Caddo Parish, La.
2. Well No. 29 of Arkansas Natural Gas Co., 2½ miles south of Vivian, Caddo Parish, La.
3. Edwards well No. 1 of Southern Oil & Gas Co., sec. 28, T. 22 N., R. 11 W., near Vivian, Caddo Parish, La.; depth, 1,040 feet.
4. Well No. 130 of Southwestern Gas & Electric Co., SE. ¼ NW. ¼ sec. 34, T. 18 N., R. 14 W., near Shreveport, La.; depth, 1,000 feet.
5. Well on L. B. Phillips lease of Southwestern Gas & Electric Co., sec. 12, T. 17 N., R. 15 W., 10 miles west of Shreveport, La.; depth, 1,000 feet.
6. Well No. 2 on Mosely lease of Southwestern Gas & Electric Co., sec. 9, T. 12 N., R. 12 W., 1 mile west of Naborton, La.
7. Well on Anglin lease of Robinson Oil & Gas Co., Mexia-Groesbeck field, Tex. Collected by G. C. Matson; see U. S. Geol. Survey Bull. 629, p. 102, 1916.
8. Well No. 1 on Mackey lease, near Corsicana, Tex. Collected by G. C. Matson.
9. Well No. 1 of Caddo Oil Fields Co., near Oil City, La., depth, 2,260 feet.
10. P. H. Youree well No. 3 of Gulf Refining Co. of Louisiana, sec. 33, T. 17 N., R. 14 W., south of Shreveport, La.
11. Casing-head gas from well No. 15 on Marston lease of Gulf Refining Co., sec. 13, T. 13 N., R. 11 W. near Abington, Red River Parish, La.
12. Well No. A-1 on Sample lease of Producers Oil Co., De Soto Parish, La. Collected by C. A. Dally, jr. of Reserve Natural Gas Co.

The samples from the Nacatoch sand are all of dry gas and show a remarkable uniformity of composition, though the true uniformity is partly obscured by the presence of air, which increases the oxygen and nitrogen content of some of the samples and decreases the methane, which is the important combustible constituent in all the gases. The air-free samples (Nos. 3, 5, and 7) which contain no oxygen, carry methane in remarkably uniform amounts. The heating value of the air-free samples is also fairly uniform. The sample from the older sand in the Corsicana field contains some air, and its proportion of the combustible constituent methane and heating value are consequently lower.

In general composition the samples from the deep sands in northwestern Louisiana are similar to those from the Nacatoch sand with the exception of Nos. 10 and 11, which show small amounts of ethane. The methane content of the sample from the deep-oil sand in the

Caddo field (No. 9) is slightly higher than that of the best gases from the Nacatoch sand. The amount of methane in the sample from the deep gas sand (No. 12) is about the same as the average amount in the samples from the Nacatoch sand. The heating values of the gases from the deep sands are also about the same as those of the gases from the Nacatoch sand. The sample that represents casing-head gas (No. 11) has a somewhat higher heating value than any of the other samples, but this is to be expected from the fact that it contains considerable ethane in addition to the methane, for the ethane has a higher heating value than the methane.

The presence or absence of ethane (C_2H_6) has sometimes been used as a means of determining whether a sand contains oil in addition to the gas, it being assumed that if no ethane is present in the gas the sand is likely to be barren of oil, and that if ethane is found in the gas the same sand is likely to be oil producing. The unreliability of these conclusions is shown by the analyses, sample 9, which shows no ethane, having been obtained from the principal oil sand in the Caddo field; sample 10, which contains ethane, having been obtained from the sand that has furnished no oil within a radius of several miles of the gas well; and samples 1 and 2, which contain no ethane, having been obtained from a sand that supplies oil within a short distance from the gas wells.

At the senior author's request Mr. G. A. Burrell, of the Bureau of Mines, has furnished the following explanation of the importance of the test for oil absorption (see table):

> The absorption test is an arbitrary test that the bureau uses for determining the adaptability of natural gas to the making of gasoline by the compression method. We have found, for instance, that only one plant working on natural gas shows an absorption of less than 28 per cent, and this is an exceptional case where the quantity of gasoline is very low. The test is simply conducted by shaking 100 cubic centimeters of gas with 85 cubic centimeters of mineral seal oil, claroline oil, straw oil, rape-seed oil, or some similar oil. Many of these oils have the same absorption capacity. The natural gas is shaken with the oil until absorption is complete, and the percentage of oil that goes into solution is measured and called the absorption.

The gases of northwestern Louisiana compare favorably with those of California,[1] whose heating value, in British thermal units, is from 724 to 934 in the McKittrick-Sunset field, 937 in the Coalinga field, 1,047 in the Kern River field, 1,019 in West Los Angeles, 1,042 to 1,044 in the Santa Maria field, 1,100 to 1,117 in Orange County, and 1,240 in the Torrey field, in Ventura County. Two analyses of Oklahoma gases show 1,025 and 1,271 British thermal units, the former being somewhat lower than that of the northwestern Louisiana gases and the latter somewhat higher. Most of the gases obtained in Pennsylvania and West Virginia have a higher calorific value than those in northwestern Louisiana, many of them exceeding 1,200 British thermal units. The northwestern Louisiana gas, however, shows a much higher heating value than the gases of northern Texas, which range from 300 to 929 and average probably less than 775 British thermal units.

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[1] Hill, B., U. S. Geol. Survey Mineral Resources, 1913, pt. 2, pp. 1460–1461, 1914.

PRODUCTION.

OIL.

It was not possible to obtain data for determining the average or total production of oil wells in the De Soto-Red River field, but this field is made up of many small areas containing numerous large wells surrounded by barren areas. This condition, although it has made some leases unusually valuable, has resulted in the expenditure of a large amount of money in drilling dry holes. In De Soto Parish much money was spent before oil was discovered in commercial quantities, although almost every one of the earlier wells gave a showing of oil. From statistics compiled by Northrop,[1] supplemented by unpublished data by the same author, a diagram has been drawn showing the number of productive wells and dry holes in De Soto Parish from August, 1913, to June, 1916. (See fig. 19.) The incomplete statistics show that in 1915 the number of dry holes was nearly equal to the number of producing wells in that parish, but in 1913 and 1914 the number of producing wells was considerably greater than the number of dry holes, as shown by the diagram.

The total production of the De Soto and Red River fields has probably exceeded 12,000,000 barrels, but exact figures of production have not been obtained because the statistics for De Soto Parish in 1913 were combined with those for another field to avoid disclosing individual operations. The production for De Soto Parish in 1914, including a small quantity from the Pelican district, amounted to 3,834,593 barrels, and in 1915 it amounted to 1,797,175 barrels. The total production from Red River Parish has been somewhat larger, amounting to 401,622 barrels in 1914 and 6,802,349 barrels in 1915.

The diagram (fig. 19) shows the average initial daily production of new wells in De Soto Parish from August, 1913, to June, 1916. This diagram illustrates the great variation in the initial production and shows, in a general way, the effect of periodic discoveries of new areas where gushers were obtained.

The diagram showing the number of producing wells and dry holes in Red River Parish (fig. 20) indicates a much higher percentage of successful wells than in De Soto Parish. This is the natural result of the character of the sand, which is more uniform in distribution in Red River Parish than in any of the other pools in northwestern Louisiana, except on the northwest side of the Caddo field. The average initial production of new wells by months is shown on the same diagram from the time of the drilling of Marston well No. 1 to the end of June, 1916, and this diagram also shows the effect of opening new pools at intervals. The first well, Marston No. 1, had a much better yield than the average for any of the following months, though much larger individual wells were drilled in some of the other pools. After the average production of the wells in the Marston district began to decline, the opening of the district on the east side of Red River and the drilling of the large wells on the Weiss tract raised the average initial production to new high

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[1] Northrop, J. D., U. S. Geol. Survey Mineral Resources, 1914, pt. 2, pp. 1036–1038, 1915.

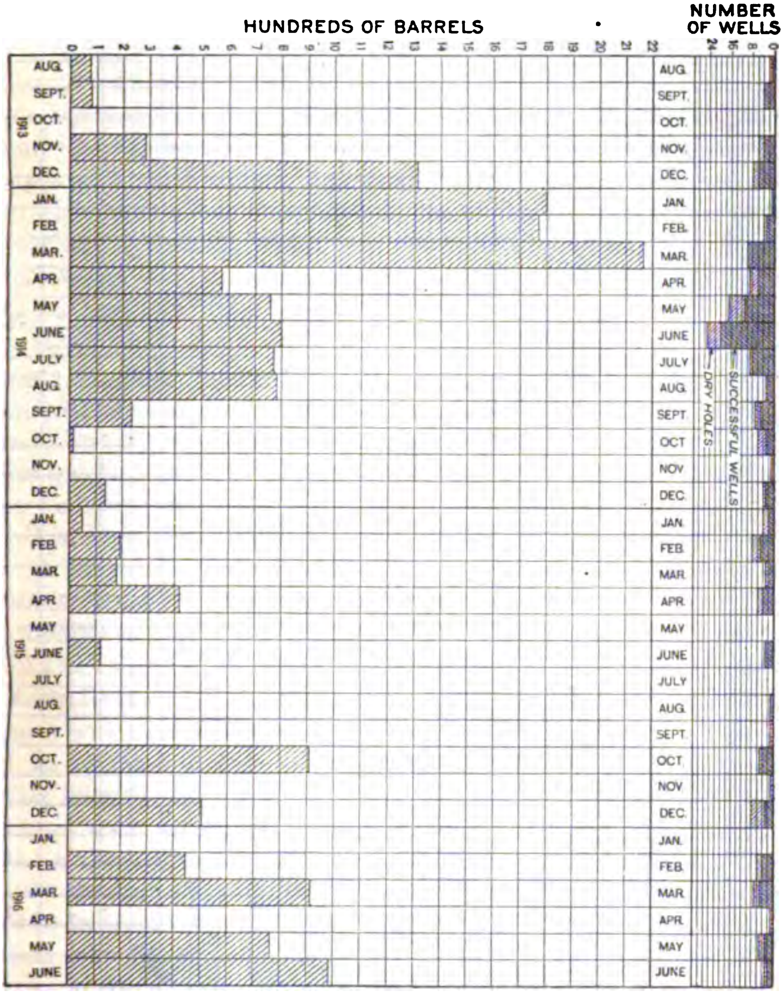

FIGURE 19.—Diagram showing number of productive wells and dry holes and average initial daily production of new wells drilled in De Soto Parish, La., from August, 1913, to June, 1916. From statistics by J. D. Northrop.

points in February and March, 1915. The decline from these high points was again arrested by the drilling of many good wells in the

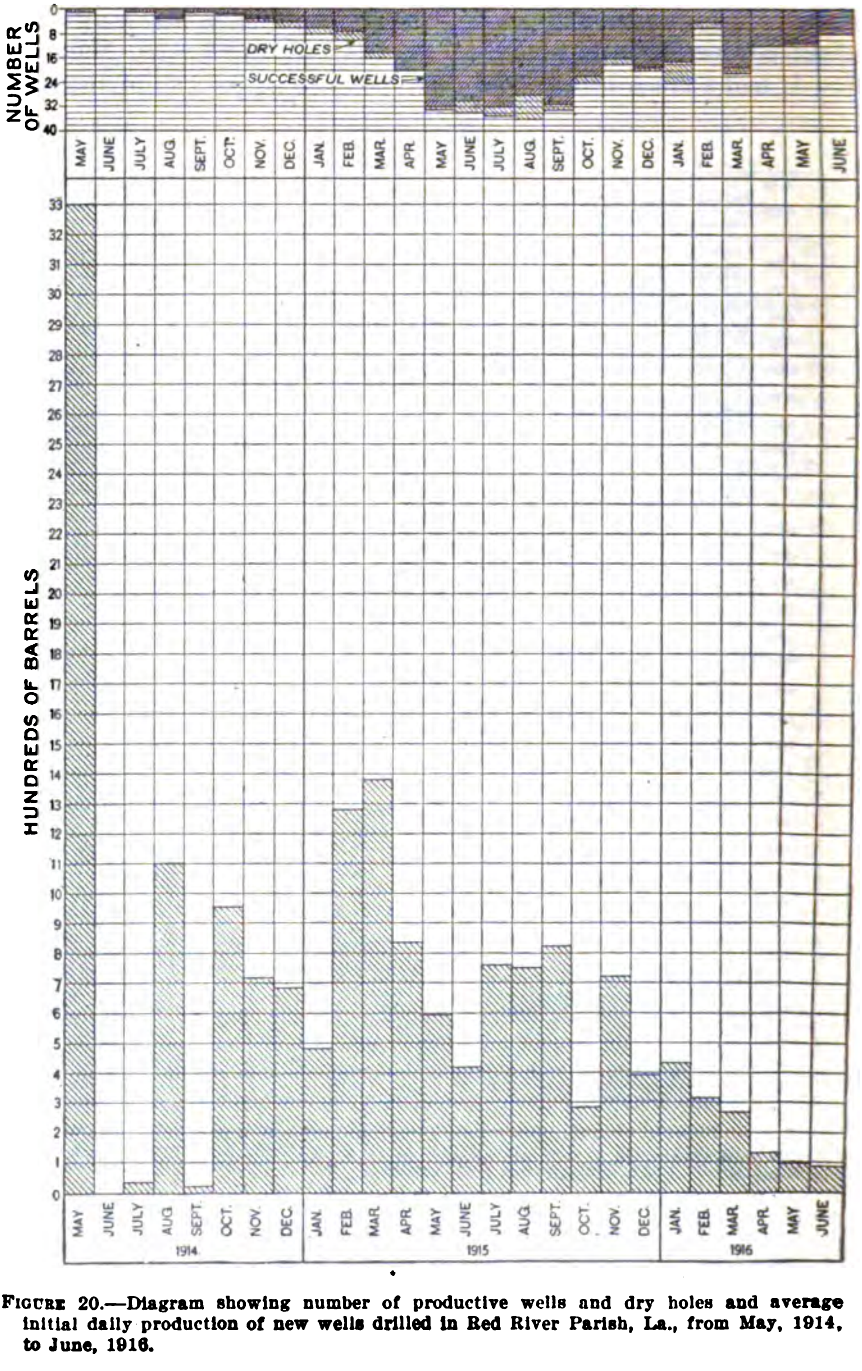

FIGURE 20.—Diagram showing number of productive wells and dry holes and average initial daily production of new wells drilled in Red River Parish, La., from May, 1914, to June, 1916.

Gusher Bend district during the later part of the summer and the early part of the autumn of 1915. In 1916 the pools in Red River Parish had all begun to decline in pressure, and the initial production fell off rapidly, the decline being uninterrupted to the close of June.

GAS.

Although natural gas was discovered at Shreveport more than a quarter of a century ago, its production in Louisiana on a commercial scale dates from the development of the Caddo oil field and the building of pipe lines to the towns and cities of northwestern Louisiana and southwestern Arkansas. The first of these lines, the one to Shreveport, was completed in the spring of 1906, and the line to southern Arkansas, which was completed to Texarkana during the following year, was subsequently extended to other towns and cities as far north as Little Rock.

Many of the early wells in the Caddo field had a very large yield, some of them being reported as having capacities of more than 50,000,000 cubic feet a day, and the large number drilled during the early history of the field led to the formulation of plans for piping the gas to New Orleans and the discussion of a project for piping it as far north as St. Louis.

The lack of an immediate market for the gas produced, together with the greater value of the oil from the same sands or from deeper sands, caused a large amount of gas to be wasted into the air in attempts to obtain oil from the wells. Gas was also used for raising oil from some of the wells that failed to flow by extending pipes into the wells and allowing the gas pressure and flow to be utilized in the same way that air is sometimes employed in pumping.

In addition to these wastes, much gas was lost through wild wells that became uncontrollable where the gas escaped around the casing. There were several of these wells. The most conspicuous was the one a short distance south of Oil City, which was finally closed in 1913 through the efforts of the Louisiana Conservation Commission. It is impossible to say what percentage of the gas from the Caddo field was allowed to escape into the air, but it was unquestionably very large.

In the summer of 1912 a well drilled at the State Fair Grounds at Shreveport obtained gas in commercial quantities, and the completion of this well was followed by the drilling of many others. The drilling of the Fair Grounds well marks the beginning of the commercial exploitation of gas from the Shreveport anticline, but this anticline has not justified the optimistic opinions that were held during the early stages of development. Most of the wells drilled on it had daily yields of only 4,000,000 to 5,000,000 cubic feet—much smaller than those of the earlier wells in the Caddo field. The maximum yield of even the best wells fell far below that of some of the early Caddo wells.

About the time that development began in Shreveport the rock pressures had fallen so low in the Caddo field that the early depletion of the supply was evident and plans were made for installing compressors in order to obtain enough gas to supply the wants of the consumers.

The early production from De Soto Parish was obtained from the same sand (Nacatoch sand) that supplied large quantities of gas in the Caddo field and at Shreveport, but the De Soto wells were more nearly comparable in yield to those of the Shreveport anticline than to those of the Caddo field. The gas from this field was first utilized by the Mansfield Gas Co. It became evident during the early stages of development that the Nacatoch sand would not supply enough gas to warrant piping to great distances from the field.

A new source of supply was discovered in De Soto Parish in the first well drilled by the Producers Oil Co. on its Sample A lease. This well, which was drilled for oil, encountered gas in a deep sand under a pressure so enormous that it could not be controlled, and the well was allowed to flow into the air for several months before it was connected with the pipe line. Subsequent drilling resulted in the completion of a number of other deep gas wells in De Soto Parish, and this led to the construction of the 16-inch pipe line from this field to Oil City, in the Caddo field. This pipe line, built by the Reserve Natural Gas Co., was completed during the autumn of 1914. Plans have recently been discussed for a pipe line to Houston, Tex., to utilize a portion of the gas from the deep sand.

The details of production of gas in northwestern Louisiana from 1909 to 1915, inclusive, are shown in the following table:

Record of natural-gas industry in Louisiana, 1909–1915.

[From U. S. Geol. Survey Mineral Resources, 1915.]

Year.	Number of producers.	Number of consumers.		Total value of gas produced.	Wells.		
		Domestic.	Industrial.		Drilled.		Productive Dec. 31.
					Gas.	Dry.	
1909	11	4,034	164	$326,245	26	10	70
1910	21	8,547	320	[a] 509,408	23	4	91
1911	27	[b] 17,964	442	[a] 858,145	36	18	116
1912	41	[b] 24,087	474	[a] 1,747,379	50	20	155
1913	57	[b] 26,424	550	[a] 2,119,948	53	24	191
1914	54	[b] 29,751	618	[a] 2,227,999	52	26	238
1915	57	[b] 30,144	597	2,163,934	35	10	253

[a] Includes the production of Alabama.

[b] Includes consumers supplied with gas piped from Louisiana to Arkansas and Texas.

AREAS OUTSIDE OF THE DE SOTO-RED RIVER FIELD.

The only folds near the De Soto-Red River field that have proved productive are in sec. 16, T. 13 N., R. 10 W., where a few wells have been drilled on and near a tract of land belonging to the Globe Lumber Co. and a few miles southwest of Pelican, near the northern boundary of Sabine Parish, where several small wells have been obtained. Neither of these pools has had a large production of oil, and the possibilities of future development do not warrant the prediction that they will ever become sources of production comparable with the best pools in the De Soto-Red River field.

In addition to these oil pools, gas has been obtained from the deep sand as far west as Spider and at various points between the Shreveport gas field and the northern boundary of the De Soto-Red River field, as well as south of the Gusher Bend fault. It is not at present possible to make a satisfactory prediction as to where the most favorable structure may be found, because a large part of this area has not been studied.

GLOBE LUMBER CO.

A few successful wells have been drilled in sec. 16, T. 13 N., R. 10 W., on and adjoining a tract of land belonging to the Globe Lumber Co. The production of most of the wells was comparatively small, ranging from 10 barrels to a few hundred barrels.

The structure of this pool has not been contoured in detail because of lack of information, but it appears to lie on the north side of the Gusher Bend fault and above the 750-foot contour on the top of the Nacatoch sand. The quality of the oil obtained from one of the Globe Oil & Gas Co.'s wells is shown in the table of analyses on page 129. There appears to be no reason for expecting a great extension of the area of production in this particular pool, because it is doubtless located on a small fold formed at about the same time as the Gusher Bend fault. There is, however, a possible extension of this fault farther to the northeast.

MANSFIELD.

In a press notice issued by the Survey in October, 1915, attention was called to some of the structural features in the vicinity of Mansfield, where it was recognized that the folds were lower and the sands deeper than in the De Soto-Red River field. In suggesting that these folds be tested by drilling, it was hoped that the conditions there might be comparable with those on the west side of the Caddo field, where the producing sand extends far below the level of the sand at the south end of the field. The well that was drilled on the anticline at Mansfield encountered the Nacatoch sand within less than 10 feet of the depth predicted in the press notice, but apparently the sand was barren of oil and gas. Further drilling on this anticline does not seem warranted unless the locations are made farther northeast, where the sand is higher.

PELICAN DISTRICT.

About 16 wells have been drilled in the southern part of De Soto Parish and the northern part of Sabine Parish, opening a small oil pool in the vicinity of Pelican. The productive wells are scattered over an area extending from a point 2 miles northwest of Pelican southward for a distance of 7 miles, in Tps. 10 and 11 N., R. 12 W. About half of the wells drilled have been productive, but they have yielded only a small amount of oil.

The stratigraphic section in this district is in every way similar to that in the De Soto-Red River field, although the section shows a smaller amount of sand. The Nacatoch sand is reached at a depth below sea level ranging from 900 feet in the northern part of the district to about 1,350 feet in the southern part. In this area it consists largely of hard sandy shale and sandstone with only a relatively small amount of loose sand. It has been productive in this area only in the Davis & Atkins well No. 1 of the Standard Oil Co., which produced heavy oil in small quantities for a few weeks. In none of the wells has it yielded a commercial flow of gas.

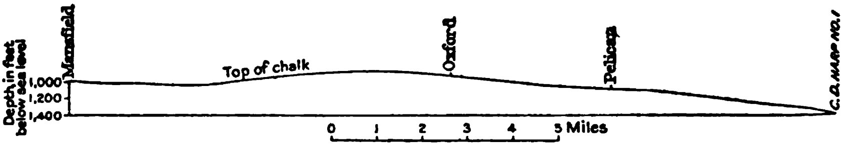

FIGURE 21.—Generalized profile showing slope of the top of the chalk and its depth below sea level from Mansfield to Pelican, La.

The productive oil sand in this field is the equivalent of the oil sand in the De Soto-Red River field, and here as there it occurs below a bed of limestone 100 feet or more thick. This sand occurs at a depth ranging from 2,800 feet in the northern part of the district to 3,200 feet in the southern part and yields from a few barrels up to 30 or 40 barrels a day. Joiner well No. 1 of the Producers Oil Co. was the best well that has been drilled in the field, and it made about 25 barrels a day six months after it was drilled. Logan well No. 2 of the Producers Oil Co. is the only gas well in the field, and the gas, which is accompanied by a large volume of salt water, is used in pumping the neighboring oil wells.

No study has been made of the surface exposures to determine the structure of the field. The wells are too far apart to admit of a determination of the details of structure from the well logs, which show a fairly uniform dip to the south of 50 to 60 feet to the mile. (See fig. 21.) From the information available, the structure is not considered favorable for the concentration of oil in large quantities.

THE IRVINE OIL FIELD, ESTILL COUNTY, KENTUCKY.

By Eugene Wesley Shaw.

INTRODUCTION.

HISTORY.

Oil and gas were discovered about 65 years ago in borings made for coal 3 to 6 miles northwest of Estill Furnace, 10 miles northeast of Irvine, Ky. Concerning these wells Lesley[1] says:

> In this valley [Hardwick's] coal has been bored for—the Devonian black slates having been mistaken for those belonging in the coal measures. In one of the borings the upper portion of the auger was blown out into the air by gas.

Another well was drilled by Samuel T. Vaughn, and Lesley[1] reports that "the auger dropped into a cavity, and when withdrawn salt water was blown out for a short time, which soon gave place to the present flow of rock oil."

Oil was known to be present at Irvine at least as long ago as 1878, for Davie,[2] speaking of this locality, says: "Several borings have been made for salt water which have at various depths struck both salt water and petroleum or coal oil of good quality."

For many years oil with some gas was obtained from a small field known as the Irvine or Ravenna field, which lies from 1 to 3 miles south-southeast of Irvine, in and around Ravenna, and was found to extend southward across Kentucky River into the valley of Little Doe Creek and northward into the hills north of Ravenna. The production and promise of the field became sufficiently great to justify the laying of a pipe line, but the rate of production gradually decreased, and a good many unsuccessful tests were made about the margin of the pool. Finally the pipe line was taken out, and the wells were abandoned, though some of them were still capable of producing a little oil.

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[1] Lesley, Joseph, Topographical and geological report of the country along the outcrop base line following the western margin of the eastern coal field of the State of Kentucky from a survey made during the years 1858–59: Kentucky Geol. Survey Fourth Rept., p. 472, 1861.

[2] Davie, W. J., Kentucky, its resources and present condition: Kentucky Bur. Agr., Hort., and Stat. First Ann. Rept., p. 340, 1878.

Early in 1915 oil was discovered on Tick Fork, 5 miles northeast of Irvine, in a test well sunk on land held by Mapel & Co. This discovery led to renewed activity, although money was spent with some caution on account of the notion that the pool was likely to be small and short lived. This notion was based on the feeling that a rather large proportion of the test wells in Kentucky were unsuccessful, or at most light and short-lived producers. As a matter of fact the proportion of unsuccessful wildcat wells does not seem to be much higher than in other States, but a good many prospectors seem to have drilled first a well of light capacity and then several dry wells, whereupon they have quit the State in disgust. The experience of oil men in the Irvine field seems to have redeemed the State's reputation, which may have declined because expectations were too high. One company is said to have obtained 118 successful wells out of 123 drilled. Although Kentucky may never be so productive of oil as Pennsylvania, yet it doubtless contains many undiscovered pools, and some of them will, like the Irvine pool, yield their oil at little cost, for they lie not far below the surface. On the other hand, there is danger that expectations will be raised too high and that money will be spent foolishly. On account of the fact that compared with the pools in West Virginia and Pennsylvania the Kentucky pools may be small and far apart, a wildcat well should be located only after a careful attempt to determine the most promising spot.

The field grew very slowly in 1915, particularly in the spring and summer. Under date of December 25, 1915, a correspondent of the Oil and Gas Journal[1] states that there are 50 producing wells and adds:

> These wells are capable of producing from 5 to 200 barrels per day. This statement would seem out of reason in view of the little that has been said about the field, were the facts not verified by actual gages. Some of the wells have been standing many months, as it has been but recently that any provisions have been made for taking care of the production. The field would have been much further advanced than it is at present, were it not for the fact that, as usual, everybody was skeptical, and the pipe line refused to make any preparations for handling the product. Consequently, those who had faith in the merits of the field had to go on investing their money without receiving any returns until recently. The Cumberland Pipe Line Co. laid a line into the field from the railroad at Irvine and installed a loading rack, together with storage tanks, and the first oil was run through its lines last week. * * *

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[1] Irvine field becomes interesting: Oil and Gas Jour., vol. 14, No. 30, pp. 20–24, 1915.

There has not been a single failure scored within defined limits, although during the two years that operations have been going on about a dozen dry holes have been drilled in territory surrounding the present field. These were mostly drilled during the early stages of developments and have served as a guidepost along the highway for the fellows who came after and were valuable in helping to establish the present defined limits of the field. Another unusual feature of the development in this field has been the lack of publicity received from the press of the country. Since the beginning of developments, more than two years ago, scarcely any mention of the field has been made. * * *

The pay is found in the top of the sand, although most of the wells are generally drilled 15 to 17 feet into the formation. The wells produce but little gas, but if drilled too deep there is danger of striking salt water. The oil itself is of 33° gravity and has a paraffin base. It is rather low in gasoline and other volatile substances, but otherwise it is a very fair grade of oil. * * *

This, however, is not the first experience Irvine has had in the oil business. About 10 or 12 years ago local parties, operating under the name of the Estill County Oil & Gas Co., opened a shallow pool just northeast of town and lying between Irvine and the present field. At one time they were operating 63 wells and sold several thousand barrels of oil to the Cumberland Pipe Line Co. The property changed hands two or three times and, after being in operation for some five or six years, eventually fell into the hands of junk dealers at Marietta, Ohio, who pulled the wells out and abandoned them.

The field grew much more rapidly in 1916, especially after about the middle of the year, when the pipe line to Campton was completed.

In the Irvine field nearly a thousand wells have now been drilled, and on the whole the decline of each has been comparatively slow. A well a third of a mile south of the discovery well, known as Hillis & Co. No. 1, Dan Rawlins, has now been pumped over two years, and its capacity is said to be nearly as great as at first.

In November, 1916, the field was producing about 5,000 barrels a day, from about 550 wells, or considerably more oil per day than all the rest of the State, which probably yielded less than 500,000 barrels in 1916. The Oil Trade Journal[1] makes the following statement concerning the field on February 20, 1917: "On a close estimate if all the wells could be pumped to their full capacity the production would be 30,000 barrels daily."

If this statement is correct and the capacity were to remain the same for a year, the field could produce in that time 10,950,000 barrels, or more than all the remainder of Kentucky has produced in the entire half century during which the oil industry has existed in that State. The field is still being vigorously developed, and its capacity for oil production is increasing. The quantity actually marketed in 1917 will probably be about 1,600,000 barrels.

In this report the continuous area underlain by oil and gas to the northeast of Irvine will be called the Irvine field, and that to the southeast the Ravenna field. Oil and gas have also been found to the southwest, in the vicinity of Station Camp, and this area will be spoken of as the Station Camp field. The bodies of oil and gas under these areas are called, respectively, the Irvine pool, the Ravenna pool, and the Station Camp pool. The report is, however, intended as a description of the Irvine field and pool, and the others will be referred to only incidentally. As oil is the main product of the field, it will be called the Irvine oil field. Other fields in the same region are shown on Plate XI.

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[1] Development is active in Kentucky: Oil Trade Jour., vol. 8, No. 3, p. 107, 1917.

GENERAL FEATURES OF THE RAVENNA OIL FIELD.

The Ravenna or, as Hoeing called it, the Irvine oil field, is described by him[1] as follows:

> *Estill County field.*—In the field near Irvine the majority of the wells start below the Waverly in the black shale itself and strike the oil rock at depths of from 70 to 90 feet. The white shale (white fire clay of the drillers) shows in places near the base of the black shale and above the oil rock, as at Ragland, and in other parts of the field is cut out. The oil rock is the Corniferous and shows in outcrop about a mile west of the oil field, along the railroad and in the town of Irvine, underlain by the Niagara shales in considerable thickness, probably 75 to 85 feet of the latter showing in a drain between the railroad depot and Irvine. In the wells a white limestone carrying fresh water is reported directly under the oil rock. An examination of the outcrop proved this to be the bottom ledge of the Corniferous. (As explained on a preceding page, by Corniferous here is meant the whole limestone formation from the top of the Niagara shale to the base of the black shale. The lower two or three ledges may belong to the "water lime" of Ohio and the Niagara limestone, below the Corniferous proper.)
>
> This Estill County field illustrates very nicely the anticlinal theory of the storage of oil in the rocks. Just at the edge of Irvine on the east is the top of what was an anticlinal fold but one which broke at the top. Between the railroad bridge over the river and the crossing at Main Street the Corniferous is exposed in the railroad cuts with the black shale over it and the Niagara shale under it. Near the bridge a fault brings the black shale down close to the river; between the bridge and town several small faults show, but the rocks are nearly horizontal; at the Main Street crossing the Corniferous shows in a cut on the west side and a fault or uplift shows very plainly at the same place. This fault brings the top of the Niagara shale on the east side of Main Street above the level of the top of the Corniferous on the west side of the street. From this point the rocks seem to rise very slightly to the east for a short distance, then bend and fall rapidly to the east (the Corniferous being below the river at the oil field) and form a long monocline with its axis just east of Irvine and the oil field still farther east and down the slope. Wells drilled on this monocline show, near the axis, dry holes; farther down the dip, oil; still farther down, oil underlain by fresh water; and still farther down the slope, salt water alone. The fresh water has evidently come in from the river, and the contents of the rocks have arranged themselves in order of their specific gravity, the salt water below and the oil above, the latter rising up the

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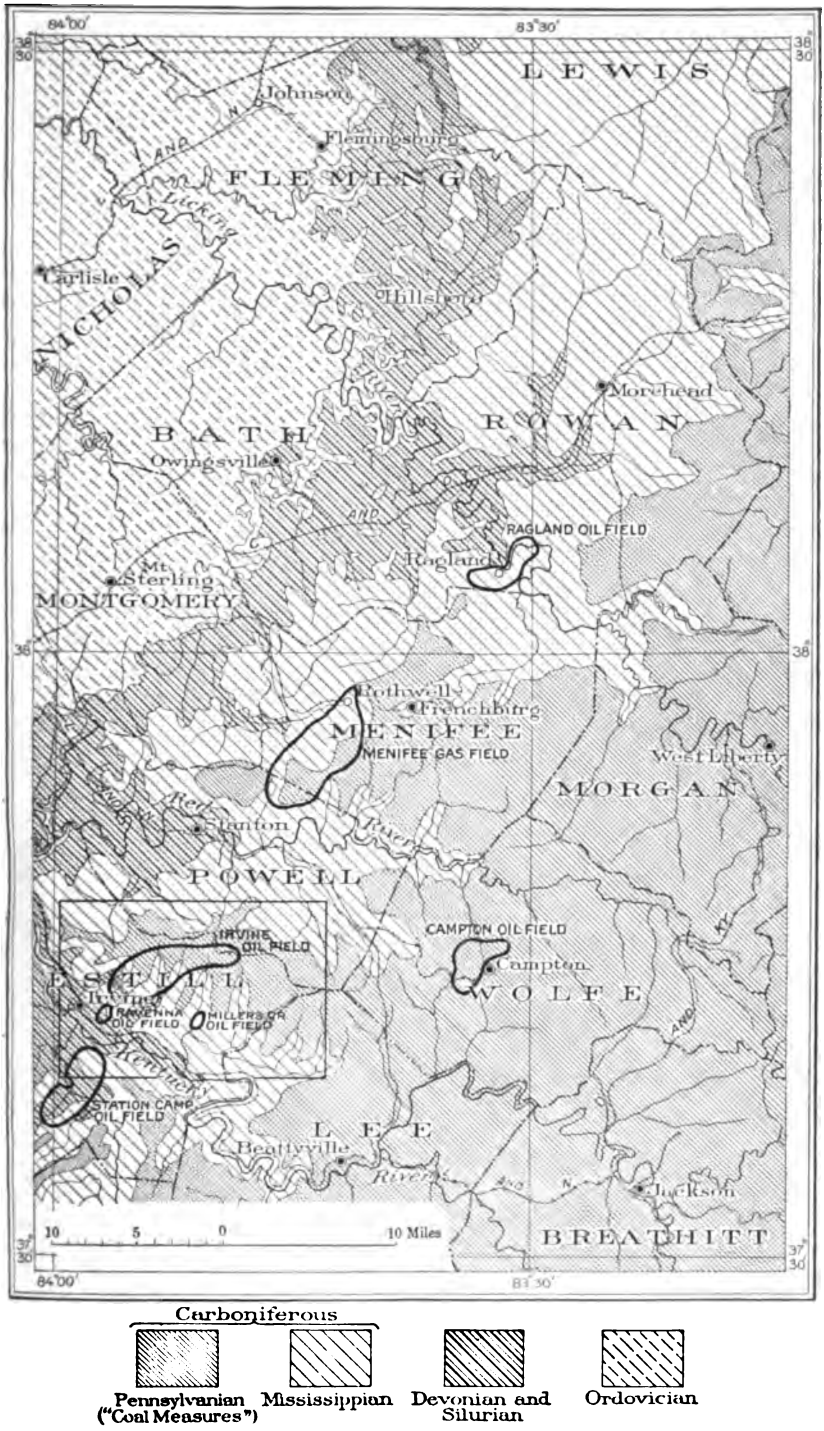
[1] Hoeing, J. B., Oil and gas sands of Kentucky: Kentucky Geol. Survey Bull. 1, pp. 53–54, 1905.



GEOLOGIC SKETCH MAP OF A PART OF NORTHEASTERN KENTUCKY.

dip only far enough to keep ahead of the water, and wells above that point giving no oil.

In 1912 M. J. Munn made a brief examination of the Ravenna field, and his unpublished notes contain the following description, which is of special value because the field is now abandoned, and any information other than scattered and more or less unrelated facts concerning it is difficult to obtain:

> The Ravenna field is on the western border of the eastern Kentucky coal field. The outcropping rocks extend from the Pennsylvanian series, which cap some of the higher hills and ridges, to rocks of Ordovician age exposed along Kentucky River and some of the principal tributaries. In the northern part of Estill County the general dip of the rocks to the east appears to be modified by a broad, low syncline whose axis trends almost due east. No geologic work was done to determine the exact form of this syncline, but its presence is clearly shown by the depth to the top of the "Corniferous" limestone, which is the oil and gas bearing bed in the Ravenna field, as well as in the gas field of Menifee County and the Ragland oil pool to the north.
>
> Considerable drilling has been done in Estill County in search for oil and gas but has resulted in the development of only a single small pool in the "Corniferous" limestone and the finding of small quantities of gas in several wildcat wells at horizons below the "Corniferous."
>
> The Ravenna field is from 1 to 3 miles southeast of Irvine, in the valley of Kentucky River and on adjacent hillsides. In this pool the "Corniferous" limestone is reached at a depth of 70 to 90 feet, the wells starting in the Chattanooga shale in the valleys. The first well was drilled in this field in 1901, and the pool was rapidly developed after that time. In 1910 it consisted of about 60 wells, none of which was producing more than a few barrels a day. In December, 1911, the pool was exhausted and completely abandoned. In this pool the "Corniferous" limestone, in which oil was found, averages about 20 feet in thickness, and the oil comes from a pay streak near the top. The pay streak is underlain by a light-colored limestone in which fresh or salt water is usually found. The "Corniferous" limestone is exposed at the top of the river bank in the town of Irvine, where certain portions show considerable traces of oil. This section of the "Corniferous" has been studied by a number of geologists, among them Kindle,[1] who has pointed out that there is an unconformity here between this limestone and the Chattanooga shale above. Kindle has shown in his paper that the Chattanooga shale at many places appears to lie conformably upon the "Corniferous," but at many other places the limestone appears to have been considerably eroded before the deposition of the Chattanooga shale.

FIELD WORK.

The investigation on which this report is based was of a reconnaissance nature, being part of a broader study of the oil and gas of the southern half of the Appalachian region, on which a general report is planned. Ten days—October 27 to November 5, 1916, inclusive—was spent in the field proper, and about five days additional in surrounding territory.

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[1] Kindle, E. M., The unconformity at the base of the Chattanooga shale in Kentucky: Am. Jour. Sci., 4th ser., vol. 33, pp. 120–136, 1912.

One of the principal objects of the field work was to determine the structure or lay of the oil-bearing stratum, for such studies throw much light on the causes of accumulation of oil pools and lead to a reduction in the percentage of unsuccessful tests through making it possible to point out promising and unpromising places to drill.

The structure of the Irvine oil sand could have been determined by running a spirit-level line to each of the hundreds of wells which furnish data concerning depth to the sand or by running level lines along the outcrops of single beds of rock that lie more or less closely parallel to the oil sand, or by taking observations of dip and strike at many places throughout the field. The first two methods would have required more time and funds than were available. The third does not yield precise results, for exact altitudes are not obtained and the strata are so nearly horizontal that it is not possible to observe strikes and dips with precision. However, the outcrops of some of the harder beds are conspicuous, and when the field work was done many of the forest leaves had fallen, and from numerous points it was possible to see a single bed for a quarter of a mile or more. The country being rugged, these outcrops curve in and out among the mountains, and by using a hand transit it is possible to determine approximately how the beds slope from place to place. The best key rock for this purpose is the Maxville(?) limestone, known to drillers as the big lime or "Mississippi lime." Another good bed is the "Corniferous" limestone, the oil sand itself, which crops out not far from the northwestern margin of the field. (See Pl. XIII, p. 166.)

Thus the field work consisted largely in making a rough survey of the outcropping beds and in obtaining from the oil operators data concerning the wells and their output. It included the determination of the general lay of the rocks in an area surrounding the field—a determination which would have been impossible from well data and spirit-level lines alone, for, although a considerable number of dry holes have been drilled outside of the field, they are scarcely sufficient to throw much light on the structure, especially as data concerning many of them can not be obtained. When an oil prospector makes an unsuccessful test he seems inclined to forget all about it as soon as possible; but data concerning such tests are of great value to both the geologist and the prospector.

From a reconnaissance topographic map of the region, made by the United States Geological Survey 26 years ago, and data concerning the altitude of the railway tracks it was possible to determine approximate altitudes throughout the field.

The main basis of the structure map (Pl. XIV, in pocket) is a series of dip observations made at points along the cliff of Maxville(?) limestone. The observations at each point consisted in sighting with the hand transit to all other cliffs of this limestone in sight and determining the apparent directions of dip. The amount of dip, if any, was estimated, and the result was plotted on that portion of the map representing the particular area covered by the observation. A large number of such observations bring to light the general form of the structure and thus fill the most essential purpose of a structure map in oil prospecting, but they do not yield data as to the exact altitude of any bed at any point.

ACKNOWLEDGMENTS.

The results of earlier work in the region by Lesley,[1] Campbell,[2] Foerste,[3] Hoeing,[4] Munn,[5] Gardner,[6] and others constituted an excellent foundation upon which to base the geologic studies. Mr. J. B. Hoeing, State geologist, and Prof. A. M. Miller, of the State University of Kentucky, also gave valuable data and suggestions. Prof. Miller very kindly furnished a sketch map showing faults which he had observed in the region. Special thanks are due to the many oil operators, who gladly put at the disposal of the Survey all the data in their possession bearing on the geology of the district and expressed a willingness to collect additional data.

GEOGRAPHY OF THE REGION.

The Irvine oil field, like the Menifee, Campton, and Ragland fields, lies in the mountainous country that borders the eastern edge of the blue-grass region of Kentucky. (See Pl. XI.) Kentucky River, which flows northwest past Beattyville and Irvine, and Licking River, which flows northwest through the Ragland field, are the main drainage lines of the region. Red River, a large tributary of the Kentucky, flows west between the Irvine and Menifee fields. The valleys of Kentucky River below Irvine, of Red River below Stanton, and of Licking River below Ragland are 2 or 3 miles wide, but upstream from these places the valleys are gorgelike and 400 to 600 feet deep.

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[1] Lesley, Joseph, Kentucky Geol. Survey Fourth Rept., pp. 439–494, 1861.

[2] Campbell, M. R., U. S. Geol. Survey Geol. Atlas, Richmond folio (No. 46), 1898.

[3] Foerste, A. F., The Silurian, Devonian, and Irvine formations of east-central Kentucky: Kentucky Geol. Survey Bull. 7, pp. 1–206, 1906.

[4] Hoeing, J. B., Kentucky Geol. Survey Bull. 1, 1905; Kentucky Geol. Survey, 4th ser., vol. 1, pt. 1, 1913.

[5] Munn, M. J., The Campton oil pool, Ky.: U. S. Geol. Survey Bull. 471, pp. 9–17, 1912; The Menifee gas field and the Ragland oil field, Ky.: U. S. Geol. Survey Bull. 531, pp. 1–20, 1913.

[6] Gardner, J. H., A stratigraphic disturbance through the Ohio Valley, running from the Appalachian Plateau in Pennsylvania to the Ozark Mountains in Missouri: Geol. Soc. America Bull., vol. 26, pp. 477–483, 1915.

GEOGRAPHY OF THE IRVINE FIELD.

LOCATION AND AREA.

The limits of the Irvine field as now developed may be described as extending from a point 1½ miles northeast of the Irvine station, in a north-northeasterly direction 5 miles to Union Hall; thence east 5 miles to a point beyond Estill Furnace; thence curving sharply southward and southwestward around to Fitchburg, a distance of about 3 miles; thence west-southwest 6 miles down the north side of Cow Creek valley and northwest a mile or so to the starting point. The length of the field is about 9 miles and its maximum width 2 miles. The farms now producing oil have an aggregate area of about 15 square miles, exclusive of scattered outside farms under which has been found oil that is not known to be connected with the Irvine pool. The field proper is now being developed most rapidly to the east.

DRAINAGE.

Most of the surface drainage of the Irvine oil field takes a southwestward course into Kentucky River by way of Cow Creek and its tributaries, Campbell Fork, Cottage Fork, and Rockhouse Fork. A small stream known as Sweet Lick Branch flows along part of the northwest border of the field, and a larger stream, Whiteoak Creek, which is about 6 miles long, has a parallel course a mile to the northwest. In a few places the northern limit of the field has been pushed across the divide and into the drainage basin of Red River.

RELIEF.

The altitude of the surface in and near the Irvine field ranges from about 600 feet in the channel of the river at Irvine, or 633 feet at the railway station, to nearly 1,500 feet at several places along the divide that runs close to the northwestern and northern boundary of the field, and a little more than 1,500 feet at High Rock, 3 miles to the northeast. This divide, like many others in the region, has a rather even crest, though in places it is as low as 1,250 feet above the sea. The ridges are strikingly uniform in height, without regard to the underlying formation, and from this it is evident that the region was once a plain and that the mountains have been made by the uplift of the region and the gradual deepening of all valleys by stream erosion.

The surface is so rugged and rocky that the shape and arrangement of the valleys and ridges are of prime importance to the oil operator, who must transport heavy machinery and pipe to all parts of the field. The valley sides are so steep that almost nowhere except on the roads can any hauling be done.

ROADS AND TOWNS.

The roads of this part of Kentucky are comparatively poor. Partly through the efforts of the oil men some of the roads in and around the Irvine field have been improved to a moderate extent, but almost no macadamizing or other dressing has been done, though limestone is abundant in all parts of the district. In Irvine some of the streets are now being surfaced with gravel and hard black shale of the Ohio (Chattanooga) formation. There is much complaint among oil operators concerning the roads, and it is said that they have offered to pay half the cost of macadamizing some of the more important roads but that such offers have not been accepted.

The main roads follow either divides or valley bottoms, and there are only a few connecting roads. The best and most traveled road of the field runs from Irvine southeast for 2 miles and thence northeast up the valley of Cow Creek. From this road branches run up the valleys of tributaries; a poor one runs up Sweet Lick Branch and a somewhat better one up Whiteoak Creek, a mile to the northwest. On the divide that forms the north and northwest boundary of the Cow Creek drainage basin there is a fairly good road, branches of which extend out along the crests of branch divides and interfinger with the roads in the valley bottoms between.

Irvine had a population of 272 in 1910, but must have several hundred more now. The Irvine magisterial district, one of six such districts in Estill County, had a population of 3,615. Ravenna, the downtown portion of which is nearly 2 miles southeast of the corresponding part of Irvine, is also growing rapidly, and the two towns are now practically one. Small stores, some of them with post offices, are fairly numerous in the country.

The Louisville & Nashville Railroad has lines connecting Irvine with Winchester, Richmond, and Beattyville and more distant points in each direction.

GEOLOGY.

STRATIGRAPHY.

GENERAL FEATURES.

The Irvine oil field is situated on the western edge of the Appalachian bituminous coal basin, just a few miles east of the eastern border of the broad area of Ordovician limestones known as the Blue Grass region of Kentucky. A southeastward dip carries the Ordovician rocks of the Blue Grass region beneath successively younger rocks of Silurian and Devonian age which crop out immediately west of Irvine. To the east these younger rocks are in turn overlain by still younger rocks of Carboniferous age (Mississippian and Pennsylvanian). The Pennsylvanian rocks are at the surface in the great Appalachian coal basin, east of which, in the western part of Virginia and Maryland and the eastern part of West Virginia, the older Ordovician, Silurian, and Devonian rocks are again brought to the surface in areas that have been subjected to intense folding and faulting.

As a general rule the formations thicken toward the east. For example, the top of the Mississippian series in the western part of the Irvine field averages about 640 feet above the oil sand or "Corniferous" limestone, whereas in the eastern part of the field it is about 700 feet above; in the Campton field, 20 miles to the east, it is about 850 feet; and in the east end of Wolfe County nearly 1,000 feet. This gradual eastward divergence of the Maxville (?) and "Corniferous" limestones is illustrated in figure 22 (p. 168).

UNEXPOSED ROCKS.

NEED OF INFORMATION.

A question which arises sooner or later in every oil field, and which is just now beginning to arise in the Irvine field, is: What chance is there of finding oil reservoirs below the present productive "sand"? Because of this question, information concerning the Ordovician and Silurian strata that underlie the oil-bearing rock becomes of great importance. Beds which may form oil reservoirs are of course of particular interest, but others for which casing must be prepared, or special drilling plans made, must also be considered. As many of the limestones of Kentucky are porous, and in places cavernous, some of them may act as oil reservoirs. Knowledge concerning these underlying beds is not very abundant. One of the best sources of information is the Richmond folio of the Geologic Atlas of the United States, which covers an area just west of Irvine. This folio, however, like many other geologic reports, discusses only the exposed rocks and hence does not describe some of the lower Ordovician strata.

SECTION IN THE BLUE GRASS REGION.

Matson's description of the rocks underlying the Blue Grass region,[1] just west of Irvine, affords much information concerning the nature of the deep-lying rocks, and the following generalized section for that region is based on his report. The comments concerning water in the several formations throw light on their possibilities as oil reservoirs.

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[1] Matson, G. C., Water resources of the Blue Grass region, Ky.: U. S. Geol. Survey Water-Supply Paper 233, pp. 14–17, 1909.

Section of hard rocks in Blue Grass region.

	Feet.
Carboniferous system:	
Waverly shale. Contains beds of greenish sandstone, which, where near the surface, yield excellent soft water. "The shale furnishes no water"	300
Devonian system:	
Ohio shale. In shallow wells it "yields an abundance of highly mineralized water. The most common mineral waters are sulphur, chalybeate, and alum"	150
"Corniferous limestone" [oil sand at Irvine]. "Usually a cherty magnesian limestone with some shale beds." In deep wells yields moderate quantities of magnesian water	30
Silurian system:	
"Blue shales and yellow limestones in places containing chert. Locally includes some sandstone." In deep wells "the limestones furnish considerable water in some localities"	60
Ordovician system:	
Richmond formation:	
Upper division, heavy-bedded gray or blue arenaceous limestones, with about 10 feet of dense calcareous shale in lower part. Locally an impure sandstone. Sandy portions yield a little water in some places	60
Middle division, blue shale, with some blue or dove-colored limestone. Rarely yields water	125
Lower division, interbedded blue limestone and shale. May occasionally yield some sulphur, brackish, or salt water	80
Maysville formation. Interbedded blue limestones and shales, the alternate layers usually thin and nodular. Most of the beds thin. "Seldom yields water at depths greater than 150 feet." Water is "apt to be brackish and contain hydrogen sulphide"	230
Eden shale. Mainly bluish shale, but upper part is commonly sandy (Garrard sandstone), and the most sandy portions generally yield water	200+
Winchester limestone. Generally yields moderate amounts of strong brines with more or less hydrogen sulphide	60+
Lexington limestone:	
Upper division, gray, crystalline and cherty (Flanagan chert). Commonly yields much salt or saline-sulphur water	75
Middle division, light-drab argillaceous limestone, with shale beds. Uppermost part, 20 to 60 feet thick, is commonly sandstone, with some phosphatic limestone. Yields some strongly mineralized water, "usually salt or salt-sulphur"	194
Lower division, heavy bedded, coarse grained, crystalline, and cherty. Yields a little salt-sulphur water	30

Ordovician system—Continued.	
Highbridge limestone. Mainly limestone, with shale lenses here and there. Little or no sandstone. Yields moderate amounts of salt and salt-sulphur water, especially from beds near top	400
Unidentified limestone, similar to Highbridge limestone	100
St. Peter sandstone. A siliceous limestone yielding large quantities of salt-sulphur water. Thickness unknown.	

SECTION IN THE RICHMOND QUADRANGLE.

Campbell's section for the Richmond quadrangle[1] is, with slight revision, as follows:

Generalized section for the Richmond quadrangle.

	Feet.
Carboniferous system:	
[Pottsville formation.]	
Corbin conglomerate lentil. Coarse pink sandstone or conglomerate	90
Lee formation. Shale and sandstone, with some coal seams. The outcrop of the coal is of minor extent	250–300
Rockcastle conglomerate lentil. Coarse conglomerate	0–175
Pennington shale [Chester group?]. Red and green shale and thin beds of limestone	0–90
Newman limestone [St. Louis and Ste. Genevieve limestones?]. Blue limestone, slightly cherty near the base	100–200
Waverly formation. Green calcareous and argillaceous sandstone. Fine green clay shale with iron concretions	350–420
Devonian system:	
Chattanooga shale. Black carbonaceous shale	110–150
Devonian and Silurian systems:	
Panola formation. Brown limestone, in places cherty, at the top; light-blue clay shale below; and coarse yellow sandstone or brown siliceous limestone at the base	1–70
Silurian system:	
Richmond formation. Blue calcareous shale with thin beds of limestone	300
Garrard sandstone Brown calcareous sandstone	70–100
Winchester limestone. Thin-bedded blue crystalline limestone with bands of calcareous shale	200–230
Flanagan chert. Thin-bedded gray limestone and calcareous shale, containing nodules and bands of chert	0–40
Lexington limestone. Thin-bedded gray limestone, containing nodules of chert at the base	140–180
Highbridge limestone. White limestone, grading downward into gray limestone and calcareous shale	190

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[1] Campbell, M. R., U. S. Geol. Survey Geol. Atlas, Richmond folio (No. 46), 1898.

DEEP-WELL SECTIONS NEAR IRVINE.

Hoeing[1] gives the following valuable discussion of exposed rocks and interpretation of records of shallow and deep wells drilled prior to 1904 in the Irvine field:

Estill County wells.

West farm, Irvine field.

[Thickness in feet.]

	1	2	3	4	5	6
Clay	14	3	25	45	4	22
Black shale (Devonian)	49	69	50	17	91	52
Oil sand (Corniferous)	20	20	18	13	16	13
	83	92	93	75	111	87

No. 7, West farm.

	Thickness.	Depth.	Geologic formation.
	Feet.	*Feet.*	
Clay	45	45	
Black shale	24	69	Devonian shale.
Hard gray lime	25	94	Corniferous limestone—Estill sand (Ragland sand).
Light gray lime	36	130	
Gray soapstone	145	275	Niagara shale.
Hard gray lime	30	305	Clinton.
Soapstone	10	315	
Gray lime	8	323	
Red lime	10	333	
Bastard gray lime	17	350	Lower Silurian (Ordovician) limestones, Hudson and Trenton groups.
Bastard brown lime	40	390	
Bastard gray lime	839	1,229	

Of the above records, the first six were taken at random from a number of records of wells drilled into the oil sand. The seventh was drilled deeper; it shows an unusual thickness of Corniferous (the limestones on outcrop about a mile west are only 25 to 30 feet thick) and also shows 145 feet of Niagara shales under the oil sand. The 30 feet of limestones under the Niagara shale are nearly all Clinton, but the upper layers may belong to the Niagara. The well went probably 250 feet in the Trenton rocks, or about to the top of the Birdseye.

A combined section made from the log of the above well (No. 7), the log of a well now being drilled on Whiteoak Creek, and a detailed section of the St. Louis, etc., given in volume 4 of the Owen reports would show the rocks from near the top of the conglomerate measures down to probably within 100 feet of the base of the Chazy limestones. The well on Whiteoak started near the top of the black shale and is down over 1,900 feet.[2] The record was not kept in the upper part but begins at 1,260 feet, which would be just about where the record of No. 7 ends. The following is the section combined as above:

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[1] Hoeing, J. B., Oil and gas sands of Kentucky: Kentucky Geol. Survey Bull. 1, pp. 69, 70, 1905.

[2] This well has since been drilled deeper, striking high-pressure gas in the Calciferous [St. Peter?] at about 1,940 feet.

Combined section in Estill County.

[The column showing depth has been recalculated to conform with other sections.]

	Thickness.	Depth.	Geologic formation.
	Feet.	*Feet.*	
Heavy sandstone	196	196	Conglomerate measures.
Shales and shaly sandstone	50	246	
Black slate	4	250	
Coal	1	251	
Gray shales	4	255	
Coal	1	256	
Shales	15	271	
Buff earthy limestones	8	279	Chester, 33 feet.
Archimedes limestone	2	281	
Gray limestone	13	294	
Calcareous shales	10	304	
Oolitic limestone	10	314	St. Louis, 150 feet.
Buff limestone	11	325	
Semioolitic limestone	22	347	
Gray limestones	12	359	
Earthy buff limestone	5	364	
Thin gray cherty limestones	24	388	
Massive limestone	22	410	
Blue limestone and shale	38	448	
Earthy yellow limestone	6	454	
Sandstones and shales	490	944	Waverly, 490 feet.
Black shale	125	1,069	Devonian shales, 125 feet.
Estill County oil sand	25	1,094	Corniferous, 25 feet.
Blue and gray shales	145	1,239	Niagara, 150 feet.
Gray lime	5	1,244	
Gray lime	25	1,269	Clinton, 53 feet.
Gray shale	10	1,279	
Gray lime	8	1,287	
Red lime	10	1,297	
Gray lime	17	1,314	Lower Silurian [Ordovician], Hudson and Trenton groups, 1,476 feet.
Brown lime	40	1,354	
Gray lime	839	2,193	
Greenish-white friable shaly sandstone	10	2,203	
Hard fine-grained limestone, dark dove-color, with occasional bands of dark-blue hard limestone.	425	2,628	
Hard gray limestone	145	2,773	
White fine-grained sand and lime	15	2,788	Calciferous [St. Peter?].
Bottom of Whiteoak well.			

The first 15 feet are Calciferous; the next 570 feet Chazy and Birdseye, with about 10 feet of fine light-green sand marking the top of the latter. Of the 839 feet of limestones above that, the lowest 200 to 250 feet constitute the Trenton limestones, and the rest, up to about 1,500, belong to the Hudson.

In another place[1] Hoeing makes the following remarks concerning what he calls the White Oak sand:

THE CALCIFEROUS [ST. PETER SANDSTONE?].

White Oak sand of Estill County.

The Calciferous until quite recently has not been known as a gas or oil bearing rock, it generally producing strong brines and mineral waters where drilled into. A well recently drilled at Elizabethtown, in Hardin County, has produced some gas from this formation at a depth of 2,300 feet. There is a flow of Blue Lick water also in this well. Another well, on Whiteoak Creek, in Estill County, has dry gas from the same formation at a depth of about 1,940 feet. The gas from this well has quite a high rock pressure, and a reported measurement by a Pitot's tube gave a volume of a little over 300,000 cubic feet per day. A second well, just completed, on Whiteoak Creek, struck a strong show of oil in the Calciferous at a little greater depth than the gas in the first well. The drilling was carried a little deeper and a strong flow of salt water encountered.

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[1] Hoeing, J. B., op. cit., p. 58.

ORDOVICIAN SYSTEM.

The Ordovician system, which includes the strata from about 300 feet to about 2,000 feet below the surface at Irvine, consists largely of limestone, most of which is probably too compact to serve as an oil reservoir. Near the top, however, and also at the base there are sandy strata. The sandstone near the top is limy and on the whole hard and compact, but here and there it probably has connecting pores of sufficient size to form an oil reservoir. The sandstone at the base is probably equivalent to the extensive and widely known St. Peter sandstone of the upper part of the Mississippi Basin. It is generally calcareous and is probably the formation called Calciferous in eastern Kentucky.

Throughout most of its extent the St. Peter sandstone yields either an abundance of good, fresh water or a small quantity of highly mineralized water, but not the ordinary salt water of oil fields. "Blue Lick," or sulphur water, is commonly reported, and shows of oil and gas are found here and there. Two deep tests near Ragland seem to have reached the St. Peter sandstone at depths of 2,558 and 2,599 feet. The strata from 400 to 600 feet below the top of the system are commonly shaly or consist of alternating shale and limestone. In Kentucky the Ordovician system is exposed throughout an area over 100 miles across, extending from points a few miles west of the Irvine field north and northwest to Ohio River and west nearly to Louisville.

EXPOSED ROCKS.

OCCURRENCE.

Very good outcrops of many of the formations immediately underlying the surface in and around Irvine are found in the vicinity of Rock House Knob. In this hill the portion of the Maxville (?) limestone represented is about 80 feet thick, the "Waverly" about 400 feet, the Ohio shale about 90 feet, and the oil sand about 10 feet.

In his third report Owen[1] gives a similar section of rocks exposed "between low water of the Kentucky River and the top of Rock House Knob, capped with sub-Carboniferous limestone."

Overlying and younger rocks cap the hills in the eastern part of the Irvine field, and older strata appear in the valley bottoms to the northwest.

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[1] Owen, D. D., Kentucky Geol. Survey Third Rept., pt. 1, p. 138, 1857.

SILURIAN SYSTEM.

In the region around Irvine the Silurian system is about 300 feet thick and consists mostly of shale. It includes almost all the strata between the oil sand of the Irvine field ("Corniferous" limestone) and the top of the great limestone mass of the Ordovician system and is exposed north and northwest of Irvine. The lowermost 50 or 60 feet consists of alternating beds of impure and semicrystalline limestone and shale, which grade down into the sandy uppermost portion of the Ordovician. The central portion of the Silurian is mainly gray shale, which here and there shows tints of red, purple, and pink. In the upper part of this central portion there are alternating beds of limestone and shale. The uppermost third of the system is mainly gray shale but includes a few beds of limestone. The stratum of principal importance to the oil operator is a sandstone near the top, which is lacking in many parts of the area. Owing to an unconformity, its position below the oil sand of the Irvine field is also irregular. The sandstone is commonly 20 to 30 feet thick and would furnish a good reservoir for oil or gas. Most of the limestones of the Silurian appear too compact for oil or gas accumulations.

Foerste,[1] who studied the succession of rocks in this region with considerable care, divides the exposed portion of the Silurian into the Brassfield (Clinton) limestone, about 15 feet thick, at the base, and the Crab Orchard division above; the Crab Orchard he further divides into the Indian Fields and Alger formations. The lower part of the Brassfield limestone is thick bedded and the upper thin bedded, with a few clay layers. Foerste's Indian Fields formation is described as consisting of 10 or 12 feet of limestone overlying 4 or 5 feet of clay and his Alger formation as consisting of about 100 feet of clay with a bed of limestone 1 to 2 feet thick 12 to 15 feet above the base. Foerste calls the lower clay member of his Alger formation the Lulbegrud clay, the upper member the Estill clay, and the limestone between the Waco limestone. All three are very well exposed on the lower slopes of hills along the lower 2 or 3 miles of Whiteoak Creek, from 1 to 3 miles north of Irvine. These divisions can be readily identified and followed in the outcrops around Irvine and can be fairly readily recognized in drilling.

The layers that would seem most likely to contain oil where the structure and other conditions are favorable are the 20 to 30 foot sandstone lying, where present, 50 feet or less below the top, a limestone lying about 100 feet from the top and one or two limestones near the base. The Waco limestone of Foerste, lying about 60 feet below the top (or base of the oil sand of the Irvine field) is not

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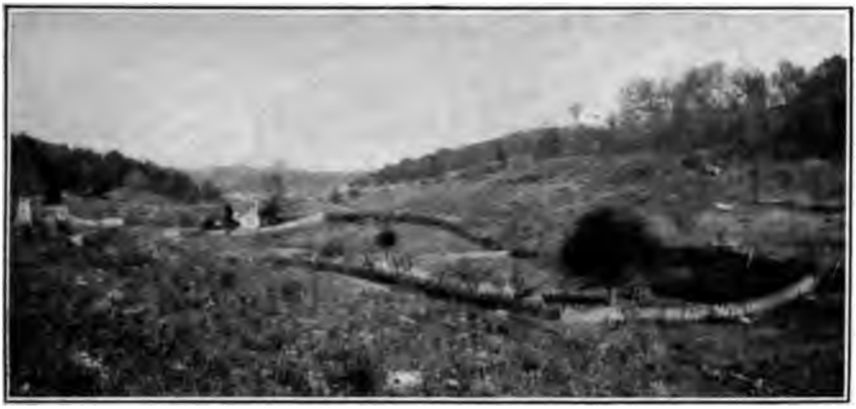
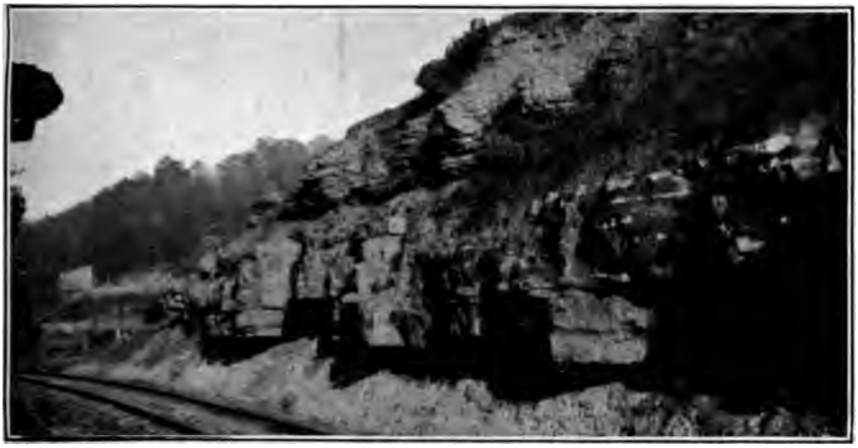
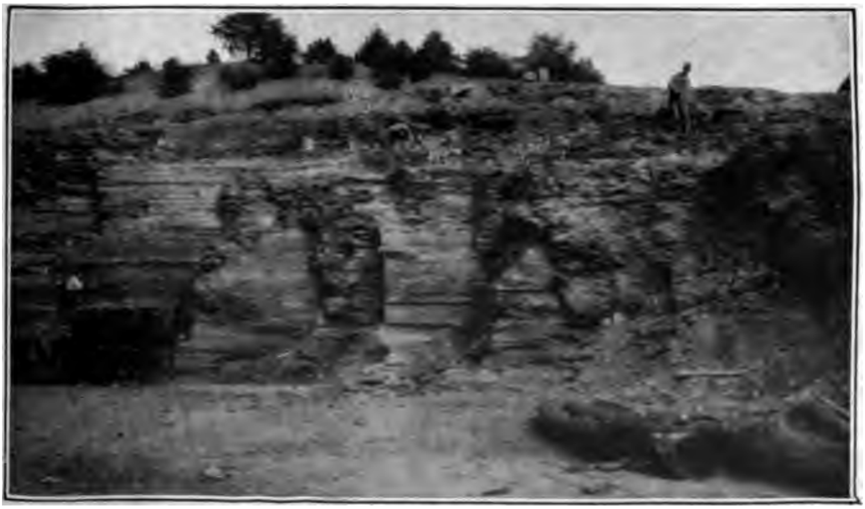
[1] Foerste, A. F., Kentucky Geol. Survey Bull. 7, pp. 10–58, 1906.



A. COMPARATIVELY GENTLE BUT ROCKY SLOPES WITH SINK HOLES DEVELOPED ON STRATA ABOVE MAXVILLE (?) LIMESTONE, 2 MILES WEST-SOUTHWEST OF FITCHBURG.



B. CHARACTERISTIC APPEARANCE OF "CORNIFEROUS" LIMESTONE IN RAILWAY CUT JUST NORTH OF IRVINE.



C. QUARRY IN BLACK OHIO SHALE, IRVINE.

COMMON SURFACE EXPRESSION OF DIFFERENT STRATA IN IRVINE OIL FIELD, KY.

promising as an oil-bearing stratum, for it is both thin and compact and is inclosed in thick beds of noncarbonaceous clay. This limestone, however, is magnesian and porous, at least in places.

The uppermost Silurian rocks may be seen at the surface in railroad cuts and the bottoms of gullies in and around Irvine. One of the best exposures is in a railroad cut a mile north of Irvine. The middle and lower portions appear down the river to the northeast, and the whole system is exposed on the valley sides a little below the mouth of Red River.

DEVONIAN SYSTEM.

"CORNIFEROUS" LIMESTONE (BOYLE LIMESTONE OF FOERSTE).

The lowest and oldest Devonian formation of the Irvine oil field is the oil sand itself, which is really a magnesian limestone or dolomite. It has been variously known as the Corniferous limestone, Devonian limestone, Boyle limestone, Columbus limestone, and, incorrectly by drillers, Clinton limestone. It is of about the same age as the Columbus and Delaware limestones of central Ohio. Its fossils are said by Butts[1] to resemble those of the Delaware limestone more than those of the Columbus, and it may be that the representative of the Columbus is missing, for there is an unconformity at or near the base of the limestone.

In thickness this limestone shows a wide range. In railroad cuts in Irvine and in hillside exposures from 1 to 4 miles north of Irvine it is less than 15 feet thick. (See Pl. XII, *B*.) To the east, however, logs of oil wells show 30 or 40 feet or even more. Elsewhere in Kentucky its thickness is as low as 1 foot, and in places it may be lacking. On the whole, it thins toward the south and west and thickens toward the north and east. Not far south of Irvine it is cut out by an unconformity at the base of the overlying black shale. In the Campton field it is probably 200 feet thick. A limestone about 780 feet thick on Lick Creek, about 5 miles northwest of Gallup, in Lawrence County, is believed to belong to this formation.

The limestone generally has a porous sandy texture and contains many small cavities, some of them lined with crystals. It is rather heavy bedded and is much jointed, so that on weathering it falls into somewhat rectangular blocks a few feet across. At some places, particularly a mile or two northwest of Irvine, it is very cherty but at others it contains little chert. Several metallic and other minerals were observed along joint cracks and in cavities associated with faults. Marcasite, a sulphide of iron, is a common constituent.

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[1] Butts, Charles, oral communication.

Galena and sphalerite, lead and zinc sulphides, were found a mile northwest of Irvine, and barite was seen at several places. Peter[1] states that the first copper ore found in Kentucky was obtained at Irvine. The metallic minerals yield glittering grains in drill cuttings. For example, samples of the oil sand from a well 850 feet deep on a farm owned by Frank B. Russell, three-fourths of a mile south of Furnace post office, contain many fragments of marcasite and a few of sphalerite.

This limestone is easily recognized in well drilling, for it is overlain and underlain by soft whitish clay shale and is the first limestone below the hard Ohio black shale. It constitutes the oil sand of many fields in eastern Kentucky. It has sometimes been called Clinton sand, but the position of the true Clinton sand is considerably lower. In some parts of the region around the Irvine oil field the limestone is said to be wanting, and in drilling in such places a lower limestone may be identified as "Corniferous" by mistake, for the clay shales above and below the "Corniferous" are very similar. The "Corniferous" is perhaps more likely to be confused with the Waco limestone of Foerste than with any other bed, but where the two are exposed on the same hillside great differences are generally apparent.

The limestone is in only a few places petroliferous throughout its thickness, and these places are, so far as known, where it is comparatively thin. The oil and gas bearing portion, or "the pay," as it is called, varies considerably in position and thickness from well to well. On the whole it seems thicker and farther below the top of the formation in the eastern part of the Irvine field than in the western part, but in the extreme eastern portion two "pays" are reported. In color the "pay" is one shade or another of brownish gray. The oil-bearing portion of the rock is firmly cemented, commonly showing much recrystallization, though it is full of minute cavities, most of which are intercommunicating. In this respect it contrasts with some other limestones of the southern Appalachian region, which carry small quantities of oil in large cavities and fissures. Some portions, however, are fine grained. The coarse-grained crystalline limestone commonly shows a strong pinkish tinge, but most of the limestone is light gray and acquires a brown stain on weathering.

The chemical composition of a somewhat argillaceous and very cherty portion of the oil sand is indicated by the analyses given in the following quotation from a report by Peter:[2]

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[1] Peter, Robert, Second chemical report on the ores, rocks, soils, coals, mineral waters, etc., of Kentucky: Kentucky Geol. Survey Second Rept., p. 162, 1857.

[2] Peter, Robert, A summary of the chemical analyses of ores, rocks, soils, clays, marls, iron furnace products, mineral waters, etc., of Kentucky: Kentucky Geol. Survey Fourth Rept. for 1858–59, pp. 141–142, 1861.

No. 951. Limestone (hydraulic?), labeled "Hydraulic limestone? 2 miles west of Red River Iron Works, Estill County, Ky. (Devonian)." A brownish-black or dark umber-colored fine-granular rock; easily broken; does not adhere to the tongue. Powder of a light umber color.

Composition of three limestones, dried at 212° F.

	No. 949 (argillaceous limestone).	No. 950 (limestone shale).	No. 951 (hydraulic limestone).
Carbonate of lime	27.980	37.480	36.580
Carbonate of magnesia	19.022	22.927	19.792
Alumina and oxides of iron and manganese	9.660	6.160	6.260
Phosphoric acid	.246	.182	.079
Sulphuric acid	.544	1.368	1.561
Potash	.618	.695	.482
Soda	.296	.372	.231
Silex and insoluble silicates	38.480	28.580	28.240
Water and loss	3.154	2.236	[a] 6.775
	100.000	100.000	100.000
Moisture loss at 212° F	.700	.700	.740

[a] This includes some bituminous matters.

Although these limestones contain more siliceous and aluminous matters than the best water limes, they are worthy of trial as hydraulic cement.

A sample of the oil sand from a well in the eastern part of the field was submitted to George Steiger, of the United States Geological Survey, to determine the magnesium and calcium carbonates. The sample was made up from drill cuttings obtained by the writer at the well immediately after it was finished, and as the finer fragments of rock that were washed out of the samples in bailing are probably of the same composition as the coarser fragments, the figures are believed to represent the composition of the oil sand at this well and are also believed to be in a general way representative for the field. The portion insoluble in hydrochloric acid, however, may consist partly of fragments of overlying shale that had fallen to the bottom of the well. In any case the analysis shows that the oil sand at this place, at least, is practically a dolomite and not limestone in the ordinary sense. The pure mineral dolomite consists of calcium carbonate, 54.35 per cent, and magnesium carbonate, 45.65 per cent. Roughly, dolomite has almost five-sixths as much magnesium carbonate as calcium carbonate, whereas the oil sand of the Irvine field seems to have only about three-fourths as much.

Partial analysis of composite sample of oil sand from Huff gas well, near Estill Furnace, Ky.

[George Steiger, analyst.]

Insoluble in HCl	24.7
FeO	2.4
CaO	22.3
MgO	14.3
CO_2	34.3

Probable combinations.

Insoluble in HCl	24.7
$CaCO_3$	40
$MgCO_3$	30.2
$FeCO_3$	2.3
FeO	.9

Throughout most of its extent in and around the Irvine oil field the oil sand probably contains at least 15 to 20 per cent of magnesium carbonate, and its porosity and consequent suitableness as an oil reservoir are probably due to the process by which the magnesium carbonate was introduced, for magnesian limestones are commonly porous and sandy in texture.

OHIO (CHATTANOOGA) SHALE AND OLENTANGY (?) SHALE.

The next formation above the "Corniferous" limestone is the peculiar hard black fissile shale, from 125 to 150 feet in thickness, which is well known to drillers because of its striking nature, particularly its color and brittleness. It is well exposed at the bases of the mountains around Irvine and in a belt 5 to 10 miles wide extending many miles northeast and southwest of Irvine; in fact, a belt surrounding the great area of Ordovician rocks above described extends nearly to Louisville and far beyond Cincinnati.

Generally the "Corniferous" limestone is immediately overlain by a bed of soft light-gray or bluish-gray clay shale 5 to 10 feet thick, and this in turn is overlain by 5 to 10 feet of hard sandy light-colored mudstone. In some places the hard mudstone is lacking, and in a few places the black shale rests directly upon the limestone, both light-colored beds being lacking. Here and there, as 4 miles northwest of Irvine, the basal part of the black shale is interstratified with two or three of the upper beds of limestone, with lenses of light-colored clay shale. On the whole the clay shale is persistent and probably performs an important function in sealing in the oil of the limestone below. It seems to be indistinguishable from a bed under the black shale in central Ohio known as the Olentangy shale, and, as Foerste[1] has suggested, the two are probably equivalent. They resemble each other in color, hardness, and stratigraphic relations and in carrying locally rather large crystals of marcasite. Well records indicate that eastward from Irvine this clay shale gradually increases in thickness.

The great overlying mass of black shale is perhaps the most striking formation in a region where all the formations are rather impressive. It is remarkably uniform in make-up and appearance and is found in every well that penetrates to its horizon throughout the broad region of its occurrence, a region that covers thousands of square miles in the Appalachian and other oil fields. Some of the wells in the Irvine field report variations in the color and hardness of the shale, and some departures from uniformity were observed in outcrops, but such differences are slight and of small extent. (See Pl. XII, *C*.)

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[1] Foerste, A. F., The Silurian, Devonian, and Irvine formations of east-central Kentucky: Kentucky Geol. Survey Bull. 7, p. 288, 1906.

In eastern Tennessee and Kentucky and adjoining territory, where this formation is generally 5 to 125 feet thick, it has been named the Chattanooga shale, from a typical exposure at Chattanooga, Tenn. In Ohio and Pennsylvania, in some parts of which this shale is thousands of feet thick and has several distinct subdivisions, it is known as the Ohio shale. The region of transition from the northern to the southern phase is in northeastern Kentucky.

Although the Ohio (Chattanooga) shale is here classed as Devonian, some geologists[1] believe that the uppermost part is Carboniferous.

The opposing view that the black shale is altogether Devonian is set forth by several writers, among whom should be mentioned particularly Kindle,[2] who describes in considerable detail some features of the strata that crop out around Irvine.

Gas and oil showings in the black shale are often reported. Hoeing[3] says:

> The black shale, wherever tested under cover, carries a large percentage of oil disseminated through it and furnishes the oil for numerous oil springs along its outcrop. When drilled through, it often gives shows of oil and gas all the way through it, especially at points where a hard layer in the shale forms a cap or shell. In other States it has been found to be a reservoir for low-pressure gas in moderate quantities, but in Kentucky it has so far, with but one notable exception, given neither gas nor oil in large amounts. The structure of the shale itself is not favorable for the accumulation of oil in reservoirs unless somewhere a sandstone should be found embedded in it.
>
> The exception above referred to is the well-known Meade County field, where gas was found in the black shale and piped to Louisville.

CARBONIFEROUS SYSTEM.

Mississippian series.

"WAVERLY" FORMATION.

Overlying the black Ohio shale is from 400 to 450 feet of soft olive-colored, drab, or bluish shale which contains many sandy layers and a few lenses of fairly clean sandstone and thin beds of limestone. This shale is equivalent to the "Waverly group" of Ohio and probably to the Pocono formation of Pennsylvania, which includes the famous Big Injun oil sand.

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[1] Williams, H. S., On the southern Devonian formations: Am. Jour. Sci., 4th ser., vol. 3, p. 398, 1897.

Grabau, A. W., Types of sedimentary overlap: Geol. Soc. America Bull., vol. 17, p. 609, 1906.

Morse, W. C., and Foerste, A. F., The Waverly formations of east-central Kentucky: Jour. Geology, vol. 17, p. 176, 1909.

Ulrich, E. O., The Chattanoogan series with special reference to the Ohio shale problem: Am. Jour. Sci., 4th ser., vol. 34, pp. 157–183, 1912.

[2] Kindle, E. M., The unconformity at the base of the Chattanooga shale in Kentucky: Am. Jour. Sci., 4th ser., vol. 33, pp. 120–136, 1912.

[3] Hoeing, J. B., The oil and gas sands of Kentucky: Kentucky Geol. Survey Bull. 1, p. 50, 1905.

In some places immediately above the Ohio black shale is a thin porous limestone which is commonly sandy. This is probably equivalent to the Beaver Creek "sand," an oil-bearing limestone of southern Kentucky. In the Irvine field it seems to contain no oil or gas, but it may be found productive to the east, farther from its outcrop.

The central part of the formation is largely olive-colored or light-green clay shale containing many clay ironstone concretions, commonly called boulders by drillers, ranging from an inch or two to 3 feet in diameter. Many of them when broken show the yellowish metallic glitter of marcasite. Such concretions are especially abundant in Rockhouse Fork. A 2-foot layer of purplish clay shale is exposed near the mouth of this fork.

In places the uppermost part of the "Waverly" is more or less calcareous, and just northeast of the field it contains considerable shaly and fossiliferous limestone having the approximate stratigraphic position and general aspect of the Keokuk limestone of Illinois, Missouri, and other States. A collection of fossils was made and submitted to George H. Girty, with the request that he determine, if possible, whether or not they indicate that the strata are of Keokuk age, and he reports as follows:

> Fossils collected 40 feet below base of cliff of St. Louis (?) limestone 1½ miles south of High Rock and 5 miles south of Filson, Ky.:
>
> Batostomella sp.
> Cystodictya lineata?
> Orthotetes sp.
> Chonetes illinoisensis?
> Productus ovatus.
> Spirifer aff. S. grimesi.
> Athyris lamellosa.
>
> This lot appears to be of the age of the Keokuk limestone. In lithology the beds from which the fossils were obtained are more like the "Waverly group" of Ohio, and I think that they probably belong somewhere in the upper "Waverly," but the fauna is more like that of the typical Keokuk.

In Ohio the "Waverly" has been subdivided by Prosser[1] into the Logan formation, Black Hand formation, Cuyahoga formation, Sunbury shale, Berea grit, and Bedford formation, named from the top down. The Berea is a famous oil-bearing bed, named from Berea, Ohio, where it crops out and in places is quarried for grindstones.

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[1] Prosser, C. S., The classification of the Waverly series of central Ohio: Jour. Geology, vol. 9, pp. 214, 215, 1901.

Morse and Foerste[1] give the following statement and section:

> Here [at Irvine] the Bedford-Berea is 1 foot 6 inches in thickness and fossiliferous, while the Sunbury is only 3 feet. This very gradual decrease in the Sunbury should be noted, although it is much less marked than the thinning of the Bedford-Berea.

Section of Minerva Mountain, Irvine.

	Ft.	in.	Feet.
6. Sub-Carboniferous limestone: Yellowish sandy-like limestone, lying at the extreme top of the hill			1
5. Upper Waverly series, not divided			344
Covered interval	60	6	
Thin-bedded buff argillaceous sandstones; which weather to thin shaly pieces; *Taonurus*	17	0	
Layers of massive buff argillaceous sandstone; *Taonurus* abundant	24	0	
Buff argillaceous sandstones, weathering to shales; *Taonurus*	17	0	
Covered interval	225	6	
4. Cuyahoga formation, top not determined			144
Brownish ferruginous and calcareous nodular layer of sandstone		6	
Indurated bluish to pinkish argillaceous shales with ferruginous nodular layers	69	6	
Soft bluish argillaceous shale with ferruginous nodular layers, slightly covered (top of Linietta clay)	63	6	
Layer of brownish argillaceous sandstone, which breaks up into shaly layers	2	0	
Soft bluish to pinkish argillaceous shales with small phosphatic nodules	8	6	
3. Sunbury shale: Black fissile carbonaceous shales			3
2. Bedford-Berea			1½
Argillaceous shales with phosphatic nodules		2	
Black fissile carbonaceous shales		3	
Dark argillaceous shales, with some carbonaceous material		6	
Gray calcareous and argillaceous shales, slightly fossiliferous		2	
Yellowish calcareous and argillaceous shales, the upper part very fossiliferous		5	
1. Ohio shale: Black fissile carbonaceous shales, with an occasional softer argillaceous layer. Practically all exposed to the highway			94½

The "Waverly" formation underlies the surface of valley sides and hill slopes throughout the Irvine field and much surrounding territory. It is readily identified by its light olive or greenish-gray color, together with its dominant soft shaly nature, great thickness, and position between the black shale below and the "Mississippi lime" or big lime above. The lower part of it and the upper part of the underlying black shale are well exposed at the mouth of Cow Creek and around the base of the mountain immediately to the east. Other parts are more or less well exposed at many places throughout the field and surrounding country but nowhere on mountain tops and in valley bottoms except in the eastern part. Compared with other formations, however, it is, because of its softness and weak nature, poorly exposed.

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[1] Morse, W. C., and Foerste, A. F., The Waverly formations of east-central Kentucky: Jour. Geology, vol. 17, pp. 172–173, 1909. See also Kentucky Geol. Survey Bull. 16, serial No. 19, pp. 46–47, 1912. Also Foerste, A. F., The Bedford fauna at Indian Fields and Irvine, Ky.: Ohio Naturalist, vol. 9, pp. 515–523, 1909.

The upper part of the formation is more or less sandy, and the amount of sand seems, on the whole, to increase upward to the top. This sandy portion is approximately if not exactly the same as the Big Injun sand of the drillers of West Virginia, Ohio, and Pennsylvania.

Hoeing[1] and Morse and Foerste[2] have discussed the possibility of finding oil in the "Waverly" of Kentucky, but as the formation is mostly above drainage level in and around the Irvine field, it probably contains no oil here.

MAXVILLE (?) LIMESTONE.

At the top of the Mississippian series is 50 to 175 feet of limestone, with here and there a bed of hard bluish or drab shale and generally soft sandstone of varying fineness of grain. This limestone is probably the same as the Maxville limestone or Big lime of West Virginia and adjacent oil regions, and the Newman limestone of the Richmond folio of the Geologic Atlas of the United States and other reports on neighboring areas to the west. It seems to be the sole representative in the Irvine field of several formations in the oil region of Illinois, including the St. Louis and Ste. Genevieve limestones, and the overlying beds of the Chester group. (See Pl. XII, *A*, p. 156.)

In other regions where it is known to occur the St. Louis limestone is almost everywhere cherty and jointed, carries *Lithostrotion canadense*, commonly gives rise to sink holes, and is comparatively resistant to erosion, so that it stands forth in bold cliffs. A member of the Maxville (?) limestone at Irvine, lying at or near the base and including about 50 feet of heavy-bedded limestone, so closely resembles the St. Louis elsewhere that it is provisionally regarded as equivalent to that formation. It is more or less cherty and jointed; the characteristic fossil referred to was found in it at several places, as, for example, on the Whiteoak Creek road, 1½ miles southwest of Union Hall; sink holes are fairly common where the limestone is not buried under the sandstone and shale of the overlying Pottsville formation, as, for example, in the vicinity of Estill Furnace and a mile north of High Rock; and it forms so continuous an escarpment at its outcrop that it is widely used as a farm boundary. Perhaps for a fourth or a third of the length of its outcrop this escarpment is a vertical cliff which may be seen for miles, and hence, as there is scarcely a square mile in or near the field where it does not occur, it is of great value in structural studies. (See Pl. XV, *A*, *B*, p. 172.)

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[1] Hoeing, J. B., Oil and gas sands of Kentucky: Kentucky Geol. Survey Bull. 1, pp. 32, 46, 1905.

[2] Morse, W. C., and Foerste, A. F., Preliminary report on the Waverlian formations of east-central Kentucky and their economic values: Kentucky Geol. Survey Bull. 16, p. 73, 1912.

Above the cliff-making limestone is from 1 foot to 100 feet of limestone that consists on the whole of purer lime carbonate and contains much less silica, though it includes lenses of both shale and sandstone. The principal reason for the marked variation in thickness is an unconformity at the top. No doubt this limestone was originally at least 75 feet thick, but before the overlying strata were laid down it was exposed to the weather and extensively eroded. Its lower part is either coarsely crystalline or oolitic, resembling fish eggs. Some of it, however, is argillaceous. Like the "Corniferous" limestone it contains many button-like or beadlike sections of stems of crinoids, or sea lilies. The upper part is less pure and contains the lenses of sandstone and shale.

So far as known the lower part of this member may be equivalent to the Ste. Genevieve limestone of Missouri, which is generally oolitic and which in the Illinois oil fields is known as the McClosky sand, and the upper part to the overlying beds of the Chester group of Illinois, which consists of much sandstone, including, in Illinois, many of the producing sands, and greenish calcareous shale. Reddish and purplish tints are also common in the Chester and are to be seen at some places east of Irvine.

A collection of fossils obtained from the limestone was submitted to George H. Girty, with the request that he determine whether or not they are of Ste. Genevieve age, and he reports as follows:

Fossils collected 4 miles northeast of Irvine, Ky., on crest of ridge south of Whiteoak Creek:

Eupachycrinus? sp.
Fenestella sp.
Rhombopora sp.
Streblotrypa nicklesi.
Productus ovatus.
Girtyella indianensis.
Spirifer pellensis.
Composita trinuclea.
Cliothyridina sublamellosa.
Leptodesma sp.
Deltopecten monroensis.
Aviculipecten talboti.

Conocardium sp.
Eotrochus sp.
Griffithides sp.

This collection almost certainly belongs at the horizon of the Ste. Genevieve limestone.

Pennsylvanian series.

POTTSVILLE FORMATION.

The ridges in and around the Irvine field, particularly to the east and south, are for the most part capped with sandy strata having an aggregate thickness of 1 foot to 200 feet and belonging in the widely known Pottsville formation. The type locality of this formation is in the anthracite region of eastern Pennsylvania, but it is readily recognized in western Pennsylvania, West Virginia, Ohio, Indiana, Illinois, Kentucky, Tennessee, and other States. In the Irvine field much of it has been eroded, and what remains is mostly sandstone. Conglomerate lenses with pebbles from one-eighth to one-half inch in diameter appear here and there, as for example just south of Union Hall, and gray to black hard to soft shale occurs at many places. Here and there, as for example at High Rock, there is a bed of coal as much as 2 feet in thickness.

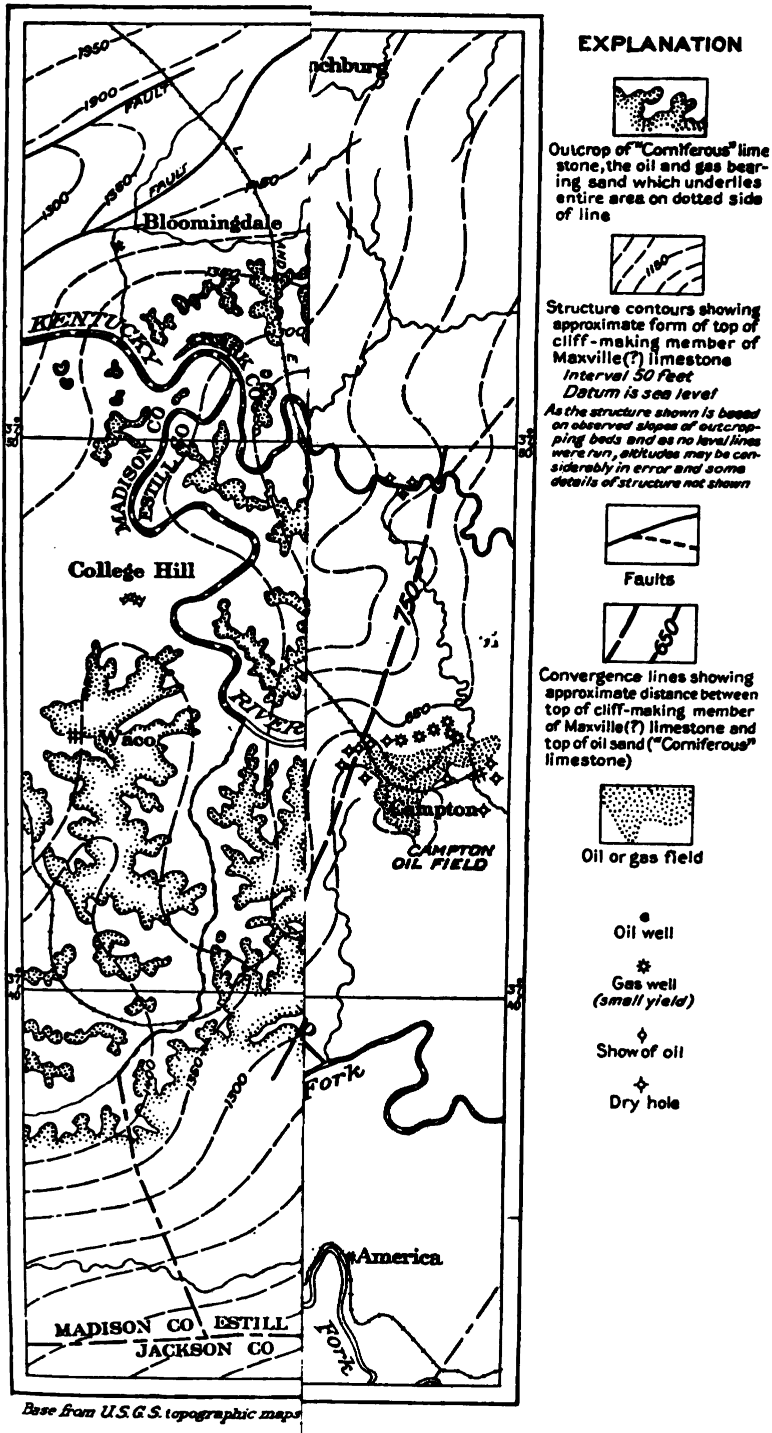
The Pottsville in the Richmond region, to the west, is said to be naturally divisible into an upper and a lower member of conglomerate and a middle one of shale. In the Irvine field sandstone is far more abundant than conglomerate, and the central shaly part of the formation, or what is left of it, is largely sandstone.

The Pottsville sandstone differs from other sandstones of the region in being on the whole more massively bedded, coarser grained, more commonly pebbly, and more generally cross-bedded, and in containing coal seams. The black carbonaceous Ohio shale 500 or 600 feet below has often been searched for coal but always in vain.

STRUCTURE.

ACCURACY OF STRUCTURE CONTOURS.

The general structure of the region is shown on the sketch map (Pl. XIII) with a contour interval of 50 feet. The contours are based on approximate dips and altitudes of various recognizable strata, the altitudes being generally taken from topographic maps. These maps, however, are of a reconnaissance character and have a rather small scale and a contour interval of 100 feet, and therefore each altitude figure may be 50 feet or more in error. Nevertheless, as these errors are not cumulative and the dips are considerable, it is believed that Plate XIII shows the general slopes and wrinkles of the strata with fair reliability.


nchburg
1950
1900
FAULT
FAULT
1300
1350
1850
Bloomingdale
KENTUCKY
CLARK CO
MADISON CO
ESTILL CO
College Hill
RIVER
Waco
750
650
Campton
CAMPTON OIL FIELD
1350
1500
Fork
America
Fork
MADISON CO ESTILL
JACKSON CO
37° 50
37° 40
EXPLANATION
Outcrop of "Corniferous" limestone, the oil and gas bearing sand which underlies entire area on dotted side of line
1150
Structure contours showing approximate form of top of cliff-making member of Maxville(?) limestone
Interval 50 feet
Datum is sea level
As the structure shown is based on observed slopes of outcropping beds and as no level lines were run, altitudes may be considerably in error and some details of structure not shown
Faults
650
Convergence lines showing approximate distance between top of cliff-making member of Maxville(?) limestone and top of oil sand ("Corniferous" limestone)
Oil or gas field
Oil well
Gas well (small yield)
Show of oil
Dry hole
Base from U.S.G.S. topographic maps

SKETCH MAP TUCKY.

The 25-foot contours shown on the larger-scale structure map (Pl. XIV, in pocket) also are not presumed to show accurately the altitude of the stratum of Maxville (?) limestone on which they are drawn, for no level lines were run to aid in the delineation, but it is believed that they show the general slopes of that limestone and also of the oil sand below, as the two are more or less nearly parallel. Although the oil prospector may desire to know the altitude of some particular point, the general form of the strata is of greater interest to him, for in Kentucky, as in many other regions, oil is found in areas where the rocks are higher than they are in adjacent territory in at least two directions, or where there is a more or less sharp change in dip.

One possible source of error in making such a structure map is the fact that two different cliff-making strata may be regarded as one and the same bed. Different parts of the Maxville (?) limestone are exposed in cliffs at different places, and here and there the overlying Pottsville sandstone makes cliffs which at a distance of a mile or more are in some places difficult to distinguish from the limestone cliffs. The structure maps of this report are believed to contain no errors from this source.

GENERAL SOUTHEASTWARD DIP.

The dominant structural feature of the region around the Irvine oil field is the general southeastward dip, which averages about 35 feet to the mile. This dip, together with its broader variations, is illustrated in Plate XIII. It carries the conspicuous cliff-making member of the Maxville (?) limestone from an altitude of about 1,330 feet 6 miles north of Irvine down to the river channel at about 635 feet 14 miles southeast of Irvine, 2 miles below the mouth of Sturgeon Creek. It carries the oil sand from an altitude of 630 feet above sea level at the Irvine Station to about 150 feet below sea level in the Campton oil field, a slope in an easterly direction, not directly down the dip, of 780 feet in 24 miles, or 32½ feet to the mile. In the Menifee gas field the sand has an average altitude of 400 feet above sea level, and as Campton, 15 miles to the southeast, is almost directly down the general dip, the sand thus slopes down between these two fields 550 feet in 15 miles, or approximately 37 feet to the mile.

The general strike of the beds, or the direction in which they do not vary in altitude, is evidently less than 45° east of north, for the Irvine, Menifee, and Ragland fields lie almost along a line trending N. 45° E., and the altitude of the sand above the sea decreases about 10 feet to the mile in that direction. From the Ragland field the southward slope toward the Campton field is about 20 feet to the mile, the total descent being about 440 feet in 22 miles.

In discussing the structure of this region Munn[1] says: "From the Menifee gas field due east to the wells on Toms Run, 5 miles north of Paintsville, in the central part of Johnson County, a distance of approximately 50 miles, the dip of the 'Corniferous' limestone is about 1,400 feet, or an average of about 28 feet per mile." He infers that directly down the dip the beds slope 40 feet to the mile.

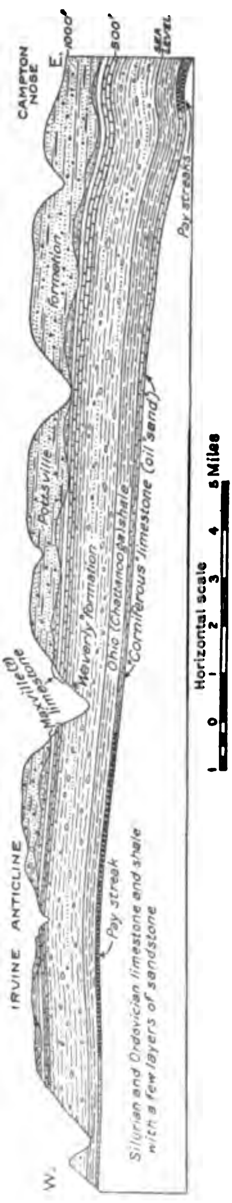


FIGURE 22.—Cross section from Irvine to Campton, Ky., showing the dip and thickening of formations in that direction, the structural features on which the oil pools are found, and the general altitude of the surface.

This general eastward dip was observed as long ago as 1838 by Mather,[2] who describes it as follows:

> As the strata of rock dips slightly to the east-southeast, in ascending the Kentucky River from Irvine to the forks we pass in succession over the rocks that overlie each other and which are seen in the hills at Irvine. At about 12 or 14 miles above Irvine we pass over the slate rock, which has plunged below the bed of the river, although at Irvine it formed the mass of the hills for 200 to 400 feet high. Limestone then succeeds in high cliffs along the banks, but this in its turn also sinks below the stream, after ascending to the rock shoals, about 3 miles below the mouth of the South Fork, and disappears from the banks of the Kentucky and its tributaries.

The lay of the rocks between Irvine and Campton, the lithologic character and thickness of various formations, and the general form and altitude of the surface are illustrated in figure 22.

A northeast-southwest profile of the oil sand is given in figure 23.

LOCUST BRANCH ANTICLINE.

Next to the general southeastward dip the most prominent structural feature of the region is the gradual change in dip from nearly east to nearly south in the general vicinity of Locust Branch and the point where Madison, Estill, and Jackson counties meet. The general structure southwest of Irvine is thus that of a southeastward-dipping monocline modified by a broad anticline that plunges rather steeply southeast. As indicated by the contours in Plate XIII, the change in direction of dip is not smooth and gradual but irregular, and as the map is only a sketch map it is probable that the irregularity is much greater than is shown. The change in dip is so irregular in detail that it is made evident only by considering in a broad way the structure of all three counties and some adjoining territory. In a district lying 2 to 10 miles west of Irvine the general dip is almost due east and about 25 feet to the mile. In the vicinity of Combs, Locust Branch, and Alcorn the general dip is nearly southeast and about 30 or 35 feet to the mile. A few miles to the west the general dip is almost due south and 40 or 50 feet to the mile. Farther west, around Berea, the dip is irregular but averages nearly south and about 30 feet to the mile. A northeast-southwest section through Locust Branch would therefore show that the beds have a general but irregular slope in each direction, though the greatest slope or true general dip would be shown by sections running from Locust Branch about east-southeast and south-southeast.

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[1] Munn, M. J., U. S. Geol. Survey Bull. 531, p. 19, 1913.

[2] Mather, W. W., Report on the geological reconnaissance of Kentucky made in 1838, p. 13, 1839.

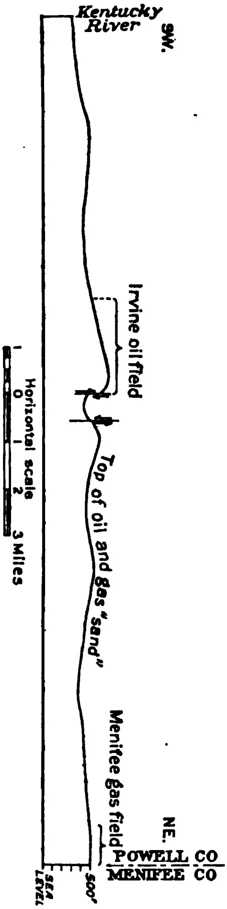

FIGURE 23.—Profile of the oil sand across the Irvine oil field, Ky., from northeast to southwest, or approximately in the direction of the strike. The profile extends from the Powell-Menifee county line, at the west side of the Menifee gas field, south-southwestward past Estill Furnace to Kentucky River near the mouth of Millers Creek.

GENERAL STRUCTURAL FEATURES AROUND IRVINE.

The general eastward dip of the northeast flank of the Locust Branch anticline, for a distance of 30 miles north of its axis, is not at all regular but swings toward the north and south and in some places is almost completely reversed or in some westerly direction. (See Pl. XIV, in pocket.) In particular along a line extending 10 miles south and 20 miles north of Irvine the average dip is a little south of east, but this dip is modified by three prominent features and many smaller ones. The larger features are an asymmetric anticline, the axis of which trends northeast from Irvine; a fault zone from half a mile to 1½ miles wide parallel to the axis of the anticline and a mile or two to the northwest of it; and a broad, shallow syncline under Clay City. For the first two the names Irvine anticline and Irvine fault zone seem appropriate, and for the third the name Stanton syncline or basin. Several secondary features are also worthy of mention, though the exact form and extent of none of them have been determined.

IRVINE ANTICLINE.

Although Munn made no survey of the country around Irvine, he suspected the existence of an anticline running east from that place, as indicated by the following statement,[1] made before the present Irvine oil field was discovered:

> The Irvine [Ravenna] and Campton fields are probably on the same anticline, which may prove to be the westward extension of a fairly definite anticline observed at a number of places in Morgan County. If careful geologic work in this area should show this to be a fact, there is a strong possibility that some of the territory along the axis of this fold between the Irvine and Campton fields will furnish small though valuable fields of oil or gas.

The axis of the Irvine anticline seems to trend almost due northeast through the downtown portion of Irvine, but 2 or 3 miles to the northeast it curves gradually to a course nearly east. It crosses the headwaters of Campbell Fork and continues across the central portion of Tick Fork. Thence, curving slightly, it crosses the divide between Cottage Fork and Rockhouse Fork, near their headwaters. Up to this point the difference in altitude of beds on the crest and the same beds at the border of the fault zone on the northwest is only 20 or 30 feet, but from this point eastward the height of the anticline seems to increase to about 50 feet, measured on the north flank, and the decline on the south flank north of Fitchburg Furnace seems to be more than 200 feet. The height of the crest above sea level also increases toward the east, although the regional dip is in that direction.

The top of the cliff-making St. Louis (?) limestone, which is represented by contours on the map (Pl. XIV), is 1,200 to 1,250 feet above sea level at Irvine, about 1,150 feet 3 to 5 miles to the northeast, and 1,300 feet in the vicinity of Estill Furnace, though its highest point is somewhat west of that place. In the next 10 miles to the east the anticline seems to broaden and gradually disappear. The northwest limb seems to be short and rather steep; the southeast limb long and somewhat irregular, sloping from 25 to 100 feet to the mile and gradually merging into a general southeast dip.

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[1] Munn, M. J., The Menifee gas field and the Ragland oil field, Ky.: U. S. Geol. Survey Bull. 531, pp. 25–26, 1913.

These features are conspicuous in and near Irvine. At Wagers station, 3 miles southeast of Irvine, the top of the Ohio shale is about at track level. To the southeast it has a medium dip, but to the northwest it rises gently for three-fourths of a mile to the mouth of Cow Creek, where it is about 15 feet above track level, or 650 feet above the sea. From this point northwestward it rises to a position of 800 feet above the sea near the downtown portion of Irvine and then declines to somewhat less than 700 feet at the schoolhouse on Sweet Lick Branch.

IRVINE FAULT ZONE.

A curious fault zone borders the crest of the Irvine anticline on the northwest. On the whole, the effect of the faulting is to drop a block of the earth's crust, from half a mile to 2 miles wide and probably more than 20 miles long, 25 to 200 feet.

The faulting was apparently first noticed by Lesley[1] in 1858. He found a fault just northwest of Estill Furnace and concluded that it had a throw of 160 feet. Former State Geologist C. J. Norwood, Prof. A. M. Miller, State Geologist J. B. Hoeing, and others have made observations at many places along its course. Gardner[2] places it on a long line of disturbance extending from the Ozarks to north-central Pennsylvania.

Along the north border of the Irvine oil field the fault zone is conspicuous at several places, though between these places are stretches through which it has not been traced continuously.

The persistent and almost unique character of the "Corniferous" limestone or oil sand makes faulting and other structural features along its outcrop easy to discern. Southeast of the Irvine station this formation is below track level and dips rather steeply to the southeast. To the northwest it rises irregularly and with slight faulting here and there (see Pl. XV, *C*), but on the whole the rise is gentle to and a little beyond the courthouse, where the limestone is 30 or 40 feet above the track. In the next half mile or so along the railway the limestone declines, with several faults of 5 to 15 feet throw, to a position only about 5 feet above the railway near the main wagon-road crossing. Here there is a much greater fault, having a downthrow on the north of perhaps 100 feet. In the next half mile the central part of the black shale crops out almost continuously at track level. A few hundred feet southeast of the mouth of Whiteoak Creek the limestone is thrown up again above track level, and thence it rises to the northwest about 100 feet in a quarter of a mile.

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[1] Lesley, Joseph, Topographical and geological report made during the years 1858–59: Kentucky Geol. Survey Fourth Rept., pp. 469–470, 1861.

[2] Gardner, J. H., A stratigraphic disturbance through the Ohio Valley running from the Appalachian Plateau in Pennsylvania to the Ozark Mountains in Missouri: Geol. Soc. America Bull., vol. 26, pp. 477–488, 1915.

This steep rise is conspicuous also a mile to the northeast along the road north of the Estill Springs Hotel. Here the northward rise is shown by comparing a roadside exposure of an inclined bed of limestone at an altitude of less than 650 feet and exposures of the same bed on hillsides a mile to the north and northwest, where the bed is about 700 feet above the sea. Two miles still farther north-northwest the bed lies at about 640 feet.

Another place where the fault zone and associated deformation are conspicuous is in the upper end of the valley of Tick Fork. From a point about 2 miles southwest of Union Hall a view to the southeast shows the St. Louis (?) limestone much lower on the southeast side of this narrow valley than on the northwest.

A good view of the fault zone is also to be had from the opposite or south side of it 2 miles west-southwest of Estill Furnace. Here the observer may stand on the cliff-making limestone and, looking northwest, see two ridges in which the limestone is more than 100 feet below his position, but 2 or 3 miles to the northwest it is as high as on the south side of the fault zone.

The displacement is striking also on the road leading north from Estill Furnace and 3 or 4 miles farther east, on the south side of High Rock. According to Prof. A. M. Miller,[1] it is well shown 3 miles east-southeast of High Rock, or just below the mouth of Barker Branch, and also 3 miles east of this point, near Glen Cairn. Prof. Miller calls the fault on the south side of the zone at Irvine the Sweet Lick fault and that on the north side the Estill Springs fault, the one immediately north of Estill Furnace the Estill Furnace fault, and the one at Glen Cairn the Glen Cairn fault.

The Irvine fault zone is nearly parallel to the axis of the Irvine anticline, and for most of their courses they are close together. The fault zone runs northeast from Irvine, curves gradually to an east or slightly north of east course from Estill Furnace to High Rock, and then, according to Prof. Miller, bends slightly south of east, and at Glen Cairn resumes an eastward course.

Apparently the zone includes two major faults, with numerous minor faults on each side. Some of the minor faults are parallel to the principal ones, and some make various angles with them. Southeast of Union Hall and along the lower course of Sweet Lick Branch there is some evidence of a fault crossing the zone diagonally.

Within the fault zone the beds are generally not far from horizontal. On the whole they seem to have a synclinal structure, the middle being lower than the sides. In some places, however, as for

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[1] Oral communication.

A. SOUTHEASTWARD DIP OF LOWER MEMBER OF MAXVILLE (?) LIMESTONE AND POTTSVILLE SANDSTONE 1½ MILES EAST OF IRVINE.

B. SOUTHEASTWARD DIP OF LOWER MEMBER OF MAXVILLE (?) LIMESTONE SHOWN BY LIMESTONE CLIFF 5 MILES EAST OF IRVINE.

C. SMALL FAULTS AND BRECCIATION OF "CORNIFEROUS" LIMESTONE AT IRVINE.

STRUCTURAL FEATURES IN IRVINE OIL FIELD, KY., APPARENT WITHOUT INSTRUMENTAL DETERMINATION.

example from 1½ to 2 miles above the mouth of Sweet Lick Branch, there are rather strong dips. Here along the bed of the creek the black shale dips from 10° to 20° in a direction somewhat west of north. This strong dip seems to indicate a monocline, which replaces the fault in part of its course. In an unsuccessful test at the schoolhouse on Sweet Lick Branch near the base of the monocline, the top of the sand was found at 148 feet below the surface and the bottom at 178 feet. Outcrops and logs of wells to the south show that the strata rise in that direction apparently without faulting.

STANTON SYNCLINE.

Although little was determined regarding the exact position, form, and extent of the Stanton syncline, the evidence that was gathered indicates its existence beyond question. This evidence consists largely in scattered observations on the geographic position and altitude of outcropping beds. In his report on the Menifee and Ragland fields Munn[1] expresses the belief that such a syncline exists, saying: "The general dip toward the southeast in the Menifee, if continued to Campton, would bring this limestone to a depth several hundred feet below that at which it is found."

Apparently this syncline plunges to the east and is terminated on the west by a north-south anticline or terrace, 8 to 10 miles west of Stanton.

MINOR STRUCTURAL FEATURES.

Slight anticlinal structure seems to be generally developed along the northwest side of the Irvine fault zone. The anticline is highest 2 or 3 miles northwest of Irvine, where it is well displayed by the outcrop of the "Corniferous" limestone and in part by the lower-lying Waco limestone of Foerste.

From a point 3 or 4 miles north of Irvine a syncline seems to extend westward 2 or 3 miles and then northward. This syncline is apparently bordered on the northeast by an irregular anticline 50 to 100 feet in height, which trends northwest from Union Hall for 5 or 6 miles and thence north along the upper end of the Stanton syncline.

Southeast of Union Hall and on the opposite side of the Irvine fault zone and anticline there seem to be two cross anticlines which converge toward the one just referred to. Indeed, if no great error has been made in their delineation, the three may be regarded as constituting a major structural feature crossing the Irvine anticline at right angles.

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[1] Munn, M. J., U. S. Geol. Survey Bull. 531, p. 14, 1913.

There seems to be a small asymmetric dome 2 miles north-northwest of High Rock or 4 miles south-southwest of Filson.

A terrace from 2 to 3 miles wide apparently extends south-southwest 10 miles from the mouth of Cottage Fork to the mouth of Jones Branch.

CONVERGENCE.

The structure map (Pl. XIV, in pocket) falls short of showing the attitude of the oil sand, not only because of the reconnaissance nature of the survey but also because it represents, as nearly as possible at the present time, the structure of a bed lying several hundred feet above the oil sand, and the two beds are not parallel. The principal departure from parallelism is due to a general westward thinning of many of the formations, as noted on page 150 and shown in figure 22 (p. 168). The precise nature of the westward convergence of the beds is not known, but apparently the distance between the top of the St. Louis(?) limestone and the "Corniferous" limestone in the Campton field is fully 750 feet, whereas at Irvine, 25 miles to the west, it is only 530 feet.

The broader structural features of the oil sand, however, are believed to be similar to those of the St. Louis(?) limestone as represented on the map. The principal difference is that all the eastward dips of the oil sand are a little greater and all the westward dips more gentle.

JOINTS.

Joints are prominent in this region, particularly in the Ohio shale and the St. Louis(?) limestone. In softer and more plastic beds, such as most of those composing the "Waverly," the joints are obscure or lacking.

Observations on joints are of interest in connection with the study of an oil pool, principally because joints may form channels for oil and gas migration and because they may throw some light on the forces that warped the rocks and produced the structural features in which the oil is found.

In the Irvine oil field most of the joints trend between north and east. Very few trending between east and south were noticed. Most of them are nearly vertical, but a few depart 30° to 50° from verticality.

OIL AND GAS.

CHARACTER OF THE "PAY."

The "pay," or oil-bearing portion of the oil "sand," differs from the remainder of the limestone or dolomite in having larger pores and in being softer or less indurated. In places it is reported to be cavernous. As this character is a product of recrystallization, it differs from similar features found in true sandstones in that it does not follow the bedding and is extremely irregular in development. After penetrating the soft, more or less sticky clay shale that overlies the oil sand the drill commonly enters a rather hard limestone or cap rock, which here and there yields water and which ranges from a few inches to several feet in thickness. Below this rock is the soft brown sandy-textured magnesian limestone which constitutes the oil reservoir. In the eastern part of the field, where the whole "sand" is thicker, oil-bearing strata are said to be found at more than one horizon.

The average thickness of the "pay" is difficult to estimate, because of its great irregularity and the fact that to avoid penetrating water-bearing rock many wells have not been deepened to the bottom of the "pay." The average thickness of "sand" penetrated, including both the oil-bearing portion and the overlying water-bearing or apparently dry rock, is probably between 20 and 25 feet. On the Isaac Henry tract, at the west end of the field, the bottoms of the wells are said to be about 20 feet below the top of the "sand," and on the Bud Rawlins tract, near by, 16 to 30 feet. On the A. M. Pasley farm, in the central part of the field, the bottoms of several wells are said to be 16, 26, 35, 23, 28, 19, 26, 23, 23, and 22 feet below the top of the "sand." Well No. 4 on this farm was carried to a depth of 80 feet below the top of the "sand" because of the poor showing of oil. These figures seem to be fairly representative of the field. Some wells have been extended 30 feet or more below the top of the "sand" and a few less than 15 feet. On the whole the "pay" is said to be farther below the top of the limestone in the eastern part of the field than in the western part, some wells penetrating 25 or 30 feet of the formation before oil in paying quantities is found.

GAS.

More or less gas has been found in a good many wells in the Irvine oil field, particularly along the northern border. A gas well about 3 miles west-southwest of Estill Furnace yielded no oil in the first week of its history, which ended at the time field work for this report was completed. It was allowed to blow off gas in the hope that oil would appear in the well in a short time. To judge by the sound of rushing gas in the casing, which is 6 inches in diameter, the well was producing 100,000 cubic feet or more of gas daily. It would not be surprising if enough gas were found in the vicinity of Estill Furnace to be worth marketing, for the Irvine anticline seems to be higher and sharper there than to the east or west.

To allow a well in an oil field to blow off gas is wasteful of gas and reduces the pressure and the ultimate yield of oil, but under present customs to close such a well imposes a hardship upon the owner without due recompense. Many such wells produce oil and become valuable assets after blowing off gas for a while. In the later part of the life of an oil field air might be pumped into some wells to take the place of gas in making the oil extraction more complete.

Most of the wells in the Irvine field yield little or no gas.

WATER.

Salt water is probably present in the lower part of the oil sand throughout much of the field, particularly the southern half, and many wells just outside the field have yielded considerable quantities of water. Along the northern border, however, wells that fail to produce oil are commonly reported altogether dry. For example, a well at the schoolhouse 2½ miles above the mouth of Sweet Lick Branch is reported to have yielded nothing at all. This well was on the north side of the fault and sharp monocline which borders the field on the north, though the difference in altitude between the oil sand here and at a producing well one-eighth of a mile to the southeast is not much over 40 feet. A fault of 30-foot throw would probably be sufficient to seal off the oil-bearing sand from the same bed on the opposite side of the fault, for the oil sand is scarcely 30 feet thick in this part of the field, and immediately above and below it are beds of relatively impervious clay shale of similar or greater thickness.

A pervious rock that is penetrated in a well and fails to yield water, oil, or gas is commonly said to be dry, but such a bed may contain much water. If the bed is lens-shaped and surrounded by impervious clay, so that no water can enter it to take the place of any that would otherwise flow out into the well, it may seem to be dry or it may yield its water very slowly. On the other hand, if the bed is not far below the surface it may be above the level of ground water and thus be really dry or rather have its pores filled with air and a very little water instead of almost nothing but water. In some places an essentially dry sandstone may lie between two beds that contain water, the upper water-bearing bed being due to perched ground water—that is, water whose natural downward movement is prevented or checked by an impervious layer. It seems probable that many if not all the deep-lying so-called dry sands in the Irvine field really contain much water, but either they are so sealed in that they can not give up their water or else they have a good outlet at a lower altitude and the hydraulic head of the water forces it to flow down the sand layer to this outlet instead of out into the well. Conditions are easily imagined under which a sand that is actually quite full of water, if the water is in motion, may take up water that is poured into a well for drilling.

Thus the failure of a well to yield water does not prove that the sand contains little or none, or even that it is not saturated, for if a layer or mass of porous rock within the earth is saturated with water but sealed off from other layers containing water, oil, or gas which can flow in to take its place its water would probably not flow out into a well. It is conceivable that if the well penetrates a great thickness of the porous bed air might flow from the well into the upper part of the bed while water flows out from the lower part, but the process would be slow because of the very low differential pressure.

The composition of the water associated with the oil at Irvine is unknown, except that it contains much sodium chloride or common salt. The water in the noted mineral springs at Irvine may come from the limestone that constitutes the oil sand, but it is certainly very different in quality from the salt water of this and other oil fields. Perhaps this difference is due to a fault between the springs and the oil-producing area and some circulation in the water of the limestone in the vicinity of the springs. The facts that mineral springs, particularly sulphur springs, are fairly common along the outcrop of the basal portion of the Ohio shale in Kentucky and Ohio and that the shale is relatively impervious, marcasitic, and commonly jointed seem to indicate that the spring water generally comes from the underlying limestone through a fissure in the shale, probably on the whole traveling far and at a comparatively slow rate, and that it gets some of its mineral matter from the limestone and some from the shale. The nature of possible oil-sand water from springs in the fault zone is indicated in analyses made by Peter,[1] who comments upon them as follows:

> The carbonates of lime, magnesia, and iron are held in solution by the free carbonic acid; or, in other words, exist in the waters as bicarbonates. The soda is also in the form of bicarbonate, which salt is not incompatible with the sulphate of magnesia present in the same water.
>
> The chalybeate water owes its name and peculiar virtues to its bicarbonate of iron, of which the red sulphur water, most distant from the house, contains traces (as doubtless the other also), and the "black sulphur" even more than the chalybeate (as tested at the laboratory). The latter contains a small portion of sulphate of alumina (alum). The change of the dissolved bicarbonate of protoxide of iron to insoluble hydrated peroxide of iron, which always takes place when these waters are exposed to the air, is the cause of the formation of the brownish deposit and their loss of virtues when they are carried any distance from the spring.

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[1] Peter, Robert, A summary of the chemical analyses of ores, rocks, soils, clays, marls, iron furnace products, mineral waters, etc., of Kentucky: Kentucky Geol. Survey Fourth Rept., for 1858–59, p. 143, 1861.

It should be borne in mind that the water may come up from a lower rock, along a fault or joint, but the facts that the salinity of the spring water is low compared with that of oil-field water in general, that in this region all the deeper wells find strong salt water, that the oil "sand" is underlain by relatively soft shale such as would be likely to seal up any fissure, and finally that springs of this sort are common near the outcrop of the "Corniferous" limestone and the basal part of the Ohio shale make it seem probable that the water really comes from the oil sand. Perhaps the fact that in all such springs the flow is copious is a further indication that the water does not come from a deep-seated source.

Some of the analyses are quoted by Chase Palmer[1] in a modified form, with further comment.

> The red sulphur water deposits ferric hydrate, the color of which has given the name to the water. Black ferrous sulphide is deposited from the black sulphur water, and from the white sulphur water a white deposit of sulphur is formed.

Composition of Estill Springs waters.[a]

[Parts per million.[b] Analyst, Dr. Robert Peter.]

	Red sulphur.	White sulphur.	Black sulphur.	Chalybeate.
Silica (SiO_2)	6.8	4.0	13	32
Iron (Fe)			48	15
Aluminum (Al)		8.5	3.6	
Calcium (Ca)	81	121	45	148
Magnesium (Mg)	26	25	11	47
Sodium (Na)	99	52	26	7.4
Potassium (K)	42	32	7.6	4.9
Carbonate radicle (CO_3)	197	24	108	72
Sulphate radicle (SO_4)	176	152	67	350
Phosphate radicle (PO_4)		Trace.		
Chlorine (Cl)	5	5.5	22	5.5
Organic and volatile matter	40	50	59	141
	715	696	410	896
Free carbon dioxide (CO_2)	325	360	263	269
Free hydrogen sulphide (H_2S)	4.5	3	35	0

[a] Kentucky Geol. Survey Fourth Rept., for 1858-59, p. 143, 1861.
[b] Obtained by computation to ionic form; results originally stated in hypothetical combinations.

Salt water in the vicinity of the Irvine field has been known at least as long as 60 years. Owen[2] says: "Borings for salt have been made on Millers Creek a few miles above its mouth and some salt water obtained."

In another report[3] Owen makes the general statement: "In the second or more ancient of these sandstones (Potsdam or Cambrian?) the water is also generally impregnated with salt, to the extent of

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[1] Palmer, Chase, Quality of the underground waters in the Blue Grass region, Ky.: U. S. Geol. Survey Water-Supply Paper 233, p. 206, 1909.

[2] Owen, D. D., Kentucky Geol. Survey Third Rept., for 1856-57, p. 140, 1857.

[3] Owen, D. D., Kentucky Geol. Survey Fourth Rept., for 1858-59, p. 28, 1861.

s in a wine gallon—mixed, however, with a variety
and mineral substances."

tion of oil-field waters is of importance in petroleum
se it promises aid in understanding the origin, the
and perhaps the quality of the oil. Oil-field waters
is ocean water; many of the strata of oil fields were
the ocean, and the suggestion thus arises that the oil-
s, so to speak, fossil sea water, or as Lane[1] has called
water—water of the ancient ocean in which the strata
d. If so, there has been little or no free circulation of
e rocks containing the salt water and oil in all the long
geologic time, and the oil was formed not far from its
osition. On the other hand, accurate chemical analyses
t the oil-field waters differ more or less from present ocean
nd presumably from the ocean water of the distant past,
r one thing, more concentrated. Whether these differences
obably been produced underground so that the oil-field water
what modified fossil sea water or whether the oil-field water
a different source is a matter of discussion. If it came from
far within the earth, perhaps the oil also came from great
The available evidence seems to indicate that neither the
nor the oil had a deep-seated source.

often suggested that salt water exerts some kind of a pickling
on the remains of organisms that become buried in the sedi-
which now constitute the strata of rock, and that the product
ousands or millions of years, under the conditions existing in
re's underground laboratory, is petroleum and gas. This hy-
esis seems rather doubtful, but the salts dissolved in the water,
larly those containing chlorine, may affect the quality of the
if they do not control its development.

SUGGESTIONS FOR PROSPECTING.

facts that the Irvine anticline seems to extend eastward for
miles beyond the proved oil territory and that the field has
en delimited on the east by dry holes[2] make the territory
Estill nd East Fork of South Fork of Red River
th of t very promising. It seems probable that
eld will ward without interruption for several

A. C., n. Inst. Proc., vol. 13, pp. 64, 125, 1908.
March, 191 e.
this para 16) several tests far east of the field
journals, proved successful, and the
tion.

The next most promising territory appears to be the Locust Branch anticline, the exact form of which has not been determined, and the third is the anticline on the north side of the Irvine fault zone. The attractiveness of this third anticline is enhanced by the tradition that a gas and oil well was drilled on it over half a century ago. The best part of it seems to be that lying a few miles a little north of west of "The Furnace." To be sure, several unsuccessful tests have been made in apparently favorable situations in this area, but that does not prove that in other favorable situations oil and gas may not be found.

On account of the fact that the oil-bearing rock lies comparatively near the surface, the structural relations of the oil pools near its outcrop may be somewhat different from those where it is far underground. If, as the writer is inclined to believe, most of the reported deep, dry sands are only apparently dry, oil pools may be more likely to occur on anticlines in them than in shallow sands, which really are partly or altogether dry.

The structure map (Pl. XIV, in pocket) shows certain minor untested structural features that may contain oil. One of these is 2 to 3 miles northwest of High Rock. Another is near the head of Laurel Rock. These suggestions are made with a large element of doubt because of the reconnaissance nature of the survey and the fact that the features are small, whereas in other regions many pools do not conform to even the larger structural features.

SURFACE INDICATIONS OF OIL AND GAS AROUND IRVINE.

In order to reduce the cost of searching for new pools it is highly important to learn what indications of petroleum existed at the surface in each field before petroleum was discovered. In the vicinity of Irvine the most significant features observable at the surface seem to have been the anticline, gas and salt water in water wells, carbonaceous rock, and the free bitumen found in a few places. As the anticline occurs in a region where the rocks are suitable for the formation of oil and its accumulation into pools it may be said to have been by far the most promising feature, and had it been discovered and mapped, and had the map been used, prospecting could have been carried on with a much better knowledge of the chances of finding oil. The development of the field would also have been more rapid and less costly if the facts concerning the structure had been fully known and used; but, on the other hand, most pools do not conform closely to the structure, and hence sooner or later, whether or not geologic data are used, the unpromising spots will be tested.

Gas and salt water are said to have been found in some water wells—for example, those referred to on page 141, and such occurrences appear to be much more common in oil fields than elsewhere. They seem to indicate a lack of free circulation of ground water—a condition favorable to the retention of oil and gas in reservoirs. Inasmuch as many rocks were formed in the sea, they must have contained salt water at first, and if they are very porous or have cracks so that the water in the ground can circulate freely through them, the salt water and any oil or gas they may contain may be washed out. For this reason it seems probable that in regions where sand is unusually abundant oil and gas pools are much less likely to be found than where clay, shale, and other impervious rocks are relatively common.

Although no tar seepages or asphaltic rocks are known around Irvine, some of the rocks give forth a bituminous odor when freshly broken, especially the Ohio shale and the underlying limestone or dolomite, which constitutes the oil "sand" of the Irvine and other fields. Oil is said to have issued in a quarry at the base of the Ohio shale near Irvine, several gallons having been obtained.

CAPACITY AND LIFE OF WELLS AND AMOUNT OF OIL STILL IN THE "SAND."

The estimation of how much more oil can be extracted from the Irvine field is a difficult problem, one reason being that little enlightening information is available from which to construct life and production curves of the wells in this field, because they have not been worked to their full possibilities, and another reason being that the pore space of the oil-bearing limestone is extremely irregular. In some places the limestone is compact; elsewhere it has an abundance of not only small pores but also cavities of various sizes. Some of these cavities may be closed, so that if they give up their oil at all it will be at so slow a rate that wells which might be supplied from them will be abandoned before the oil gets out.

PRODUCTION OF OIL.

The production of oil in the Irvine field is indicated in the accompanying diagrams (figs. 24–28) made up from data published in the Oil and Gas Journal and the Wayne County (Ky.) Outlook. The diagrams show that the number of wells and daily production of the field have grown rapidly; that the percentage of successful wells has been rather high since the development of the field got fairly started, and that the average initial production, though showing much variation, seems to show no general trend as the field is extended eastward.

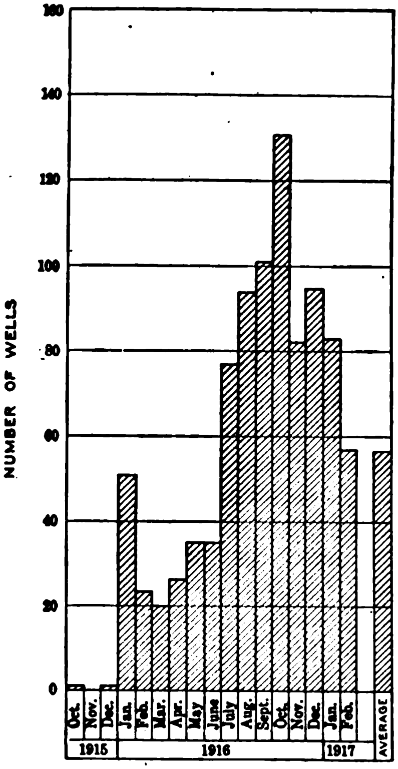

FIGURE 24.—Diagram showing number of wells drilled in and near the Irvine oil field, Ky., from October, 1915, to February, 1917.

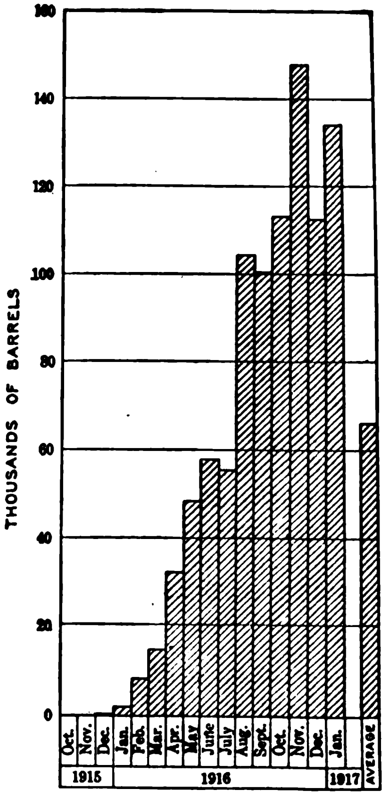

FIGURE 25.—Diagram showing production of Irvine oil field, Ky., from December, 1915, to January, 1917.

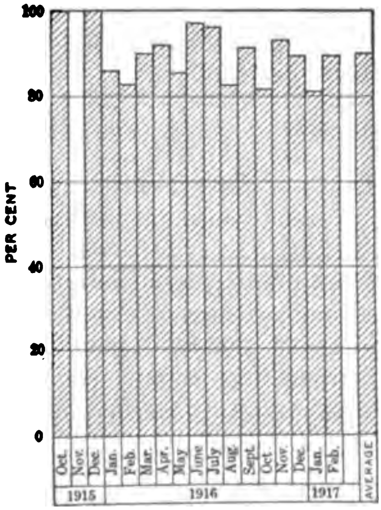

FIGURE 26.—Diagram showing percentage of successful wells in Irvine oil field, Ky., from October, 1915, to February, 1917.

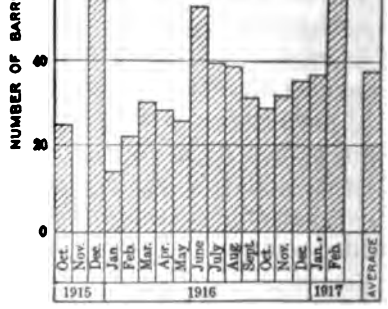

FIGURE 27.—Diagram showing average initial production of successful wells in Irvine oil field, Ky., from October, 1915, to February, 1917.

The statistics represented by the diagrams, with some later figures which have appeared since the diagrams were prepared, are given in the table on page 184.

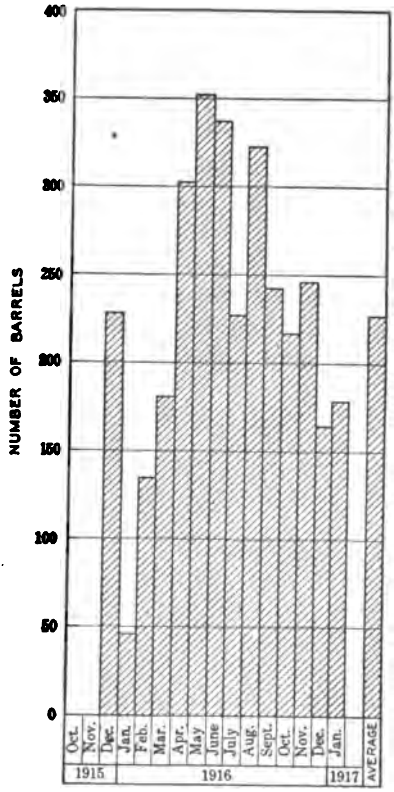

FIGURE 28.—Diagram showing production in Irvine oil field, Ky., for each month from December, 1915, to January, 1917, divided by total number of productive wells previously drilled.

The pore space of the oil "sand" is evidently extremely variable within short distances, though perhaps that of considerable bodies of the rock is fairly uniform. A specimen from an outcrop absorbed, after being dried, 25 per cent by volume of water. This percentage is probably much above the average for the oil-bearing rock, for, although the sample was selected as being approximately representative of the visible or outcropping portion of the oil rock, it probably differs from the buried portion on account of exposure to the weather, one effect of which is the gradual leaching out of the small admixture of lime carbonate in the rock.

It is evident that on account of the variations in effective or communicating pore space and the numerous small cavities, accurate estimates as to pore space can not be made from the few small fragments of the oil rock that have thus far been obtained from wells. When the shooting of wells becomes more general it will no doubt be possible to get many chunks of the rock an inch or more in diameter, from which fairly reliable determinations of pore space can be made, and from these the total quantity of oil in the rock can be estimated. Perhaps when the field is supposed to be exhausted it can be shown from the total amount of pore space in the "pay" throughout the field and the total amount of oil and gas produced that actually much oil remains in the rock as a lining of pores at that time containing water.

In any case the total pore space of the "pay" in the present productive area is apparently five to ten times as great as the total quantity of oil so far marketed, and it seems probable that the pool will be found to have an extent 30 or 40 per cent greater than the present proved area.

The initial pumping capacity of wells in the Irvine field seems to run generally between 10 and 70 barrels a day. Very few of the wells have flowed naturally. Because the marketing facilities are inadequate the production has been much below the full capacity of the wells. Practically all the oil marketed is said to be shipped through a 4-inch pipe line. Partly for the same reason few wells have been shot. It seems unlikely, however, that shooting would greatly increase the capacity of the average well and very improbable that the ultimate yield of the wells could thus be greatly increased, for the oil-bearing rock has comparatively large pores and fracturing is not greatly needed. However, many of the wells will no doubt be shot as soon as their capacity drops or shipping facilities are increased to the point where the oil obtained by a temporary increase of capacity could all be marketed.

Well data for Irvine, Ravenna, and Station Camp fields, Ky.

Month.	Number of wells completed.	Percentage of productive wells.	Average initial production of productive wells (barrels a day).	Total production (barrels).	Production for the month divided by total number of productive wells to date.
1915.					
October	1	100.0	25.0	....	....
November	....	....	....	....	....
December	1	100.0	100.0	456.00	228.00
1916.					
January	51	86.3	14.2	2,120.14	46.09
February	23	82.6	22.1	8,725.00	134.23
March	20	90.0	30.1	15,000.00	180.72
April	26	92.3	28.4	32,343.71	302.28
May	35	85.7	25.8	48,250.60	352.19
June	35	97.1	55.2	57,845.56	338.29
July	77	96.1	39.2	55,721.03	227.43
August	94	82.9	38.4	104,189.02	322.57
September	101	91.1	31.4	100,567.84	242.33
October	131	81.7	28.3	113,137.29	216.74
November	82	93.9	31.8	147,670.39	246.53
December	95	89.5	34.5	112,554.70	164.55
1917.					
January	83	81.9	36.4	133,953.24	178.13
February	57	89.5	60.4	107,341.13	118.87
March	72	81.9	55.6	145,000±	150.72
April	68	83.8	49.1	130,000±	127.57
Average	55	89.2	39.2	77,345.63	210.43

CHARACTER OF THE OIL.

The Irvine oil is dark green by reflected light; by transmitted light it is of so dark a brown as to seem opaque except where the thickness of the sample is only an eighth or a quarter of an inch. Its specific gravity is said to range from 30° to 36° Baumé, and its gasoline content is said to be so high that the oil sometimes bubbles in the tanks.

A sample of oil was collected from the Bud Rawlins farm, 2 miles northeast of Irvine, and sent to the Bureau of Mines for analysis. The returns are of especial interest because this farm lies next to the fault and also less than 2 miles from several exposures of the oil-bearing rock. The sample was collected from a freshly filled tank, and the oil came from wells Nos. 1 to 11, inclusive, except well No. 4.

Analysis of crude oil from Irvine field, Ky.

[Specific gravity at 15° C., 0.872=30.5° B. Distillation in Bureau of Mines Hempel flask. Barometer, 747 millimeters.]

Temperature (°C.).	Fractions (per cent by volume).	Total distilled (per cent by volume).	Specific gravity.
Up to 125	3.4	3.4	0.739
125-150	4.0	7.4	.773
150-175	4.9	12.3	.794
175-200	3.7	16.0	.811
200-225	4.2	20.2	.823
225-250	4.8	25.0	.831
250-275	5.7	30.7	.844
275-300	8.7	39.4	.847

ORIGIN OF THE OIL.

The source and mode of formation of petroleum are not yet known with certainty, though fairly convincing evidence has been brought forth concerning the oil of certain fields. The most prevalent opinion among oil geologists is that it is of organic origin and that most of it at least has been derived from the remains of plants rather than of animals. However, the arguments for animal origin, as, for example, the fact that oil is in many places associated with mollusk shells, have appealed to many.

To the writer it seems very probable that most petroleum is of plant origin. The two principal reasons are, first, that carbonaceous remains of plants are far more abundant than those of animals in all rocks, and, second, that the hydrocarbon-bearing portions of animals decompose far more readily and quickly than such parts of plants.

By far the greater part (probably over 99 per cent) of the carbonaceous material in the earth's crust that can be classified with certainty is of plant origin, and, except for water, plants consist principally of the elements that go to make up petroleum and natural gas, namely, carbon, hydrogen, and oxygen. The soft parts of animals also consist mainly of the same elements with more or less nitrogen, but they decompose or oxidize much more readily, and hence are much more likely to be lost in the air and surface water before being buried so deep that decomposition or oxidation ceases. The writer has had the opportunity of observing many lime, sand, and other formations in process of development, and has seen many places where plant material was being incorporated with sediment, including the great mud deposits at the mouth of Mississippi River and certain rivers in northern Europe; the lime deposits around Florida and Yucatan, the Great Salt Lake, and elsewhere; sand deposits at various places along the Atlantic coast, the Great Lakes, the smaller lakes and streams; and more or less sandy, limy, and clayey deposits in glacial and other lakes. He has seen only a few places where the soft parts of animals have been or are being buried, and at most of these places it is presumable that decomposition continues to completion. Most oils contain a little nitrogen, which is a much more abundant and characteristic constituent of animal matter than of plant matter, but the amount in petroleum is generally a small fraction of 1 per cent. Many plants contain some nitrogen, and it appears possible that some of the nitrogen in petroleum may have come from air buried with the organic mud, the oxygen having been used up in other combinations.

The fact that globules of petroleum have been observed in cavities associated with shells of sea animals does not seem significant, because petroleum is almost exclusively found in cavities or in the larger openings and pores of rocks, and it is much more reasonable to assume that the oil came from elsewhere and stopped where it found a cavity, than that a part of the flesh of a Paleozoic sea mollusk was converted into petroleum, and that the other products of the change were carried away, although presumably less easily transported, while the petroleum was left for ages precisely where it was formed, particularly as, though fossils are abundant, occurrences of globules of oil in them are rare and are confined to those which happen to have cavities.

In the Irvine field a very large quantity of carbonaceous material is included in the Ohio black shale, which contains abundant remains of plants, particularly spore cases of ferns, which may be seen on almost any slab of the shale. They form rather conspicuous black or dark-brown spots ranging from one-sixteenth to one-fourth inch in diameter, and are commonly surrounded by resinous masses, which are beyond a doubt derived from plant matter and yet are very similar in composition to petroleum.

The facts that this shale immediately overlies the oil-bearing rock, though generally the very carbonaceous portion is separated from the oil rock by a few feet of light-colored clay shale; that it is by far the most carbonaceous bed in the region; and that a petroleum heavier than that in the oil "sand" can be distilled from it make it seem extremely probable, if not almost certain, that this shale has been the source of the oil now being produced in the field. The writer knows of no oil field where the circumstantial evidence as to the source of oil is stronger than in the Irvine field. The spore cases themselves, which are beyond doubt of plant origin, have undergone a gradual slight rearrangement of their molecules that brings their composition close to that of petroleum, as is indicated when they are distilled in a closed tube. If they or in fact any portion of the shale is put in a glass tube a few inches long and closed except for a small opening at one end, and if the shale is shaken down to the opposite end and this end heated over a hot flame, gas will issue from the opening at the other end and may be ignited, while a conspicuous ring of oil distilled from the shale will form on the inside of the tube.

The conditions that determine whether oil or gas, which are composed of practically the same elements, and what variety of either will be formed when the shale is subjected to pressure for ages are not yet fully understood, but David White,[1] who has given much attention to this subject, believes that gas is more likely to predominate over oil where the pressure is greatest.

MODE OF ACCUMULATION OF THE OIL.

The next problem is to trace the oil from its original position of wide dissemination in the shale to the oil "sand" and to portions of the oil "sand" where the structure is favorable for the accumulation and retention of pools. The Ohio shale, like most other geologic formations, was laid down in water of one kind or another, and its original thickness, when it was saturated with water, was much greater than its present thickness. When great deposits of mud, particularly carbonaceous mud, are buried beneath hundreds of thousands of feet of later deposits and allowed to lie thus buried for thousands or millions of years, compacting must obviously take place. To judge by determinations of pore space made by the writer, the average carbonaceous mud that is not yet buried has 8 to 10 times as much pore space as the present Ohio shale. In the compacting process all the fluids contained in the mud which later became the Ohio shale were forced out by the most available route, whether that was down, up, or sidewise. This process has recently been discussed by Johnson.[2] In borings which the writer has made in recent carbonaceous materials no oil has been found, even in portions that have been considerably compacted. He is hence inclined to believe that the formation of petroleum does not begin until after the main compacting has been accomplished. If any were formed before, it might be carried out in whatever direction the original water was forced out.

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[1] White, David, Some relations in origin between coal and petroleum: Washington Acad. Sci. Jour., vol. 5, pp. 189–212, 1915.

[2] Johnson, R. H., The rôle and fate of the connate water in oil and gas sands: Am. Inst. Min. Eng. Bull. 98, pp. 221–226, 1915.

After most of the compacting had been accomplished the fluids contained in the Ohio shale and the overlying and underlying formations must have been shifted about a little from time to time by any further compacting that took place, by crustal movements of the earth, by changes in internal temperature, by tidal stresses, by changes in air pressure, and probably by an extremely slow direct or indirect downward migration, such as the writer suspects is common to all water under lands that attain any considerable altitude above the sea. In this way the oil and gas formed in the Ohio shale were very likely shifted somewhat, though the facts concerning their evident close confinement and the existence of salt water near the surface indicate that the migration of none of the fluids has been extensive.

According to the writer's views, the migration and separation of the oil, gas, and water are effected as follows:

The water, oil, and gas in all rocks are constantly under the influence of intermolecular attractions, which are effective through only minute distances, but which within those distances are very great, much exceeding that between the earth and a molecule. Such forces differ from substance to substance, and their general effect in a sand is to push the oil and gas into the larger pores or cavities, or at least to retain it in such places after it has arrived. Apparently the heat activity of the molecules would not profoundly modify the result. The largest pores available to the oil of the Irvine field are in the "Corniferous" limestone. As the amount of oil was insufficient to fill all the cavities in the limestone throughout its extent, the continuance of all the processes that tend to shift about fluids within the earth might very reasonably have caused the oil and gas to respond to the force of gravity, which is stronger for water than for oil, and to migrate to the places where the sand lay highest, leaving water in the lower places. As Munn[1] has pointed out, it seems impossible that in the nearly flat-lying beds of most oil fields the migration to the top of an anticline or other favorable structural feature could be accomplished by gravity alone, while all fluids were quiescent, but if the fluids were moved any considerable distance the oil and gas might during their migration accommodate themselves to gravity and get to the tops of the anticlines, and if all fluids were subject to an oscillatory motion, even if so slight as to amount to the diameter of only a few pores, the oil and gas would perhaps still migrate to the tops of the anticlines.

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[1] Munn, M. J., The anticlinal and hydraulic theories of oil and gas accumulation: Econ. Geology, vol. 4, pp. 509–539, 1909.

SHALE OIL.

It is interesting, both for the scientific purpose of a better understanding of the origin of petroleum and for the practical purpose of knowing what opportunity exists of making artificial petroleum from the Ohio shale, to know the nature and proportions of hydrocarbons which may be extracted from it. Shales from which oil may be obtained are not at all uncommon in the United States and other countries, and in some places, particularly in Scotland, the manufacture of petroleum from shale has been carried on for many years. It is said that many plants built for the extraction of oil from the Ohio shale were in operation in Kentucky and Ohio 50 or 60 years ago. Some of the petroleum in the shale may be dissolved out with ether or some other liquid in which petroleum dissolves readily, and some requires distillation; in other words, some seems to exist as petroleum in the shale, but a larger part is a chemical product of the distillation of other hydrocarbons.

A sample of the Ohio black shale from Irvine was submitted to the Bureau of Mines for destructive distillation. The test indicated that the shale would yield 7 gallons of oil and 8 gallons of water to the ton.

Samples of black shale from numerous places in Kentucky, Tennessee, Pennsylvania, Ohio, Indiana, and other States have been tested, and the results are discussed by Ashley,[1] who remarks: "According to these figures, the Devonian black shale can be expected to yield not over 10 or 12 gallons of oil, 2,000 cubic feet of gas (as a by-product), and one-third of a pound of ammonia to the ton."

The chemical composition of the shale is shown by the following analysis, by Robert Peter, of more or less weathered material collected by Owen:[2]

Devonian black slate, sifted out of soil from Thomas Carson's farm, near Irvine, Estill County, Ky.

[Composition, dried at 212° F.]

Alumina and oxides of iron and manganese	6.880
Carbonate of lime	.244
Magnesia	.433
Phosphoric acid	.310
Sulphuric acid	.132
Potash	1.101
Soda	.340
Sand and insoluble silicates	82.280
Bituminous matters, water and loss	8.300
	100.000

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[1] Ashley, G. H., Oil resources of black shales of the eastern United States: U. S. Geol. Survey Bull. 641, p. 320, 1917.

[2] Owen, D. D., A summary of the chemical analyses of ores, rocks, soils, clays, marls, iron furnace products, mineral waters, etc., of Kentucky: Kentucky Geol. Survey Fourth Rept., for 1858–59, p. 145, 1861.

The soft aluminous shales are very generally rich in potash, and where they are easily decomposable they yield a rich soil, subject, however, to be wet, heavy, or swampy, because of the considerable amount of clay present and imperfect natural drainage. When well drained, these lands may be made quite productive.

Two samples of the black shale were submitted to C. E. Van Orstrand with the request that the porosity and specific gravity be determined before and after extraction of carbon dioxide, combined water, and organic material by acid and ignition. He made the following report:

> The porosity of sample No. 1 was found to be 7.6 per cent; that of No. 2 to be 7.4 per cent.
>
> After grinding the samples until they passed through the 100-mesh sieve they were washed in petroleum ether. The sample which gave 7.6 per cent porosity was washed 12 times; the other one was washed 18 times. A washing consisted of covering the sample with petroleum ether, letting it boil for about 15 minutes, and then decanting off the petroleum ether. Petroleum ether was again poured over the sample and then poured off. The above process was then repeated. The final porosity of each sample was found to be 8 per cent.
>
> The separated grains of the shale passed through the 300-mesh sieve.
>
> A 3-gram sample of the shale was passed through a 100-mesh sieve, and then boiled for 20 minutes in concentrated hydrochloric acid. The porosity determined from the powder thus treated is 8 per cent, the same as was obtained by boiling in petroleum ether. Another 3-gram sample was passed through the 100-mesh sieve and heated 20 minutes in a Bunsen flame. The porosity determined from this final product is 19.6 per cent. The specific gravity of the powder thus treated is 2.59, and a solid cubic foot of it would weigh 161.69 pounds. A cubic foot of the shale with the 19.6 per cent of pore space emptied in the way outlined would weigh 130 pounds.
>
> This and previous tests were made by A. F. Melcher.

The shale as it lies in the earth with water and other substances in the pores probably weighs 140 to 145 pounds to the cubic foot.

NOTES ON DEVELOPMENT.

Although this report is designed primarily to be purely geologic in nature, the geology of the field is so closely related to problems of the recovery of petroleum that a few brief notes on these problems are worthy of record in this place.

As the oil "sand" lies not far below the valley bottoms, drilling is comparatively inexpensive. It is reported that the discovery well cost less than $50. The average cost of wells is, however, several hundred dollars, for most of them are deeper than the discovery well, and some have cost more than $2,000. Most of the drilling is done with machines, but derricks have been erected here and there. The general appearance of the field differs markedly from those where the oil lies at great depth, for there is no forest of derricks, but instead inconspicuous pumping jacks scattered over the more or less wooded mountain sides.

As the country is rough, it is commonly difficult to haul drilling machinery to a well site, and generally temporary roads have to be built. For a similar reason it is difficult to get a supply of water to wells at relatively high altitudes.

Many of the first wells are said to have been drilled too deep and to have penetrated a salt-water zone, which seems to underlie the oil "sand" throughout a large part of the field. Some of the early wells were also shot too heavily, several wells having apparently been ruined in this way.

It is also difficult and expensive to bring fuel to the oil wells, and many of them have, curiously enough, been drilled with gasoline costing 15 or 20 times as much as the market price of the gasoline-bearing oil, for which they were being drilled.

The connecting pores of the oil-bearing rock are relatively large throughout its extent, and the oil is under more or less pressure from gas. Hence the oil flows into the wells rapidly, and there is little need for close drilling. However, the rock varies somewhat in porosity, and hence there seems to be a possibility that small portions of the pool may be surrounded by advancing water and their oil prevented from reaching a well.

The method of advance of this water is a geologic problem of great economic importance. As the oil is taken out, air, gas, or water must flow into the pores to take its place, and the question immediately arises, How complete is the replacement? If the walls of the pores retain a coating of oil, the oil recovered may be much less than the original amount in the ground, for most of the pores are probably not over 0.002 inch in diameter and a thin coating on their walls would be a large part of their original content. It may be that the replacement is more complete with slow extraction, so that the percentage of recovery would be higher if the oil were taken out at a slower rate. The pores are extremely irregular in diameter, more so than the grains composing the sand, and it may be that some of the smallest pores retain their oil.

Few of the wells have been shot, and few flow. Partly on account of insufficient marketing facilities, there has been no effort to force wells to their full capacity. As these facilities grow better and the demand for oil increases and as the production of individual wells declines no doubt many of them will be shot and thus rejuvenated.

It is said that much more oil would have been produced if it could have been readily marketed. The outlet has been a single 4-inch pipe line, and this has been taxed to its utmost capacity, being at times subjected to a pressure, it is reported, as high as 1,100 pounds to the square inch. However, an additional pipe line is said to be in process of installation.

THE BOWDOIN DOME, MONTANA, A POSSIBLE RESERVOIR OF OIL OR GAS.

By Arthur J. Collier.

INTRODUCTION.

The Bowdoin dome is situated on Milk River, in northeastern Montana, on the main line of the Great Northern Railway between Malta on the west and Hinsdale on the east. (See index map, fig. 29.) It is about 42 miles south of the Canadian boundary, 150 miles west of the Dakota-Montana State line, and 100 miles east of Havre. The dome is a broadly arched portion of the earth's crust from which the strata dip away on all sides, its structure being a type known to be favorable for the accumulation of oil or gas in many fields. A well drilled here for water several years ago has been yielding a small flow of gas, sufficient probably for domestic use in one family, ever since, and it is thought that the region offers a chance of success to the driller of deeper wells. In 1915 a large gas well was drilled at Havre.

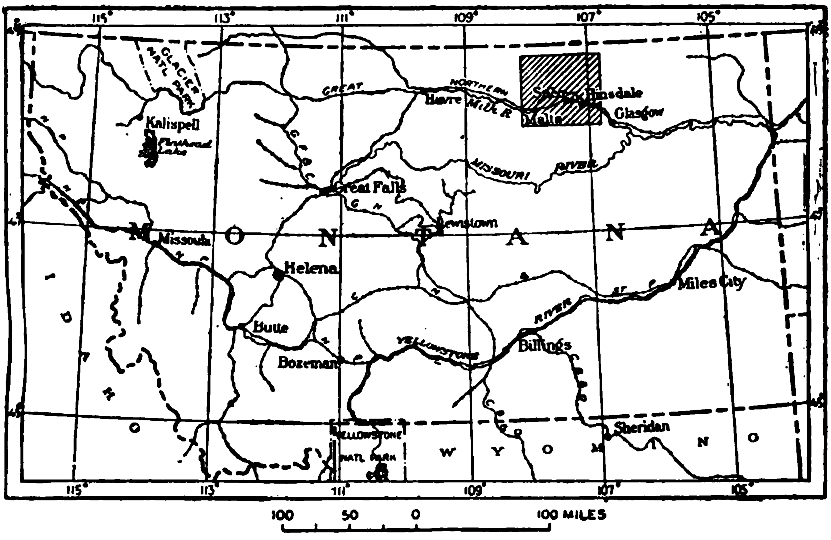

Figure 29.—Key map showing location of Bowdoin dome, Mont.

FIELD WORK.

During the summer of 1916 the writer, assisted by H. R. Bennett and Edwin T. Conant, made an extensive reconnaissance in northeastern Montana. The field work consisted of hastily riding over large areas, noting the outcrops of the formations, collecting fossils, and, whenever the presence of lignite beds or the geologic structure justified it, running traverse lines from section corners with the plane table and telescopic alidade. A section partly exposed on the east side of the Little Rocky Mountains was measured by this means, and several lines were run to determine the dips of the rocks. Many elevations were determined approximately by the aneroid barometer. A considerable part of the season's field work was applied to the examination and mapping of the Bowdoin dome.

AUTHORITIES CONSULTED.

The region has not been examined in detail by geologists, and little has been published regarding it. The stratigraphy of the Little Rocky Mountains, southwest of the dome, is described by Weed and Pirsson,[1] but their inspection was confined to the part of the mountains where gold and silver were being mined. The Larb Hills, south of the Bowdoin dome, are described very briefly by Barnum Brown[2] in his report on the "Hell Creek beds." The territory adjacent to the Canadian line is described by Dawson,[3] and a report by Pepperberg[4] sets forth the geologic conditions about 30 miles west of Malta. The region described by Pepperberg was examined again in 1915 by Stebinger,[5] who reported on its possibilities of yielding oil and gas. The Fort Peck Indian Reservation, 30 miles to the east, is covered in a report by Smith,[6] and the region north of the reservation was examined in 1915 by the writer. The occurrence of glacial drift and the preglacial position of Missouri River across the Bowdoin dome are discussed by Calhoun.[7]

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[1] Weed, W. H., and Pirsson, L. V., Geology of the Little Rocky Mountains: Jour. Geology, vol. 4, pp. 399–428, 1896.

[2] Brown, Barnum, The Hell Creek beds of the Upper Cretaceous of Montana: Am. Mus. Nat. Hist. Bull., vol. 23, pp. 823–845, 1907.

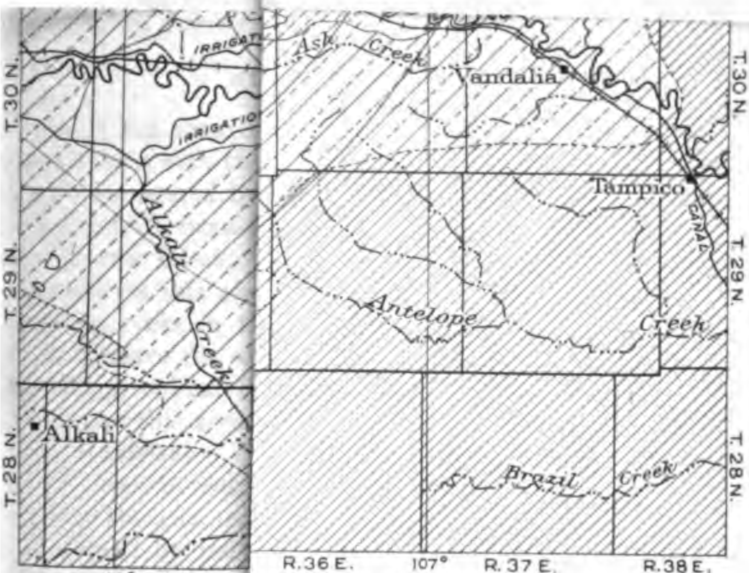
[3] Dawson, G. M., Geology of the forty-ninth parallel, British-North American Boundary Commission, Montreal, 1875.

[4] Pepperberg, L. J., The Milk River coal field, Mont.: U. S. Geol. Survey Bull. 381, pp. 82–107, 1910.

[5] Stebinger, Eugene, Possibilities of oil and gas in north-central Montana: U. S. Geol. Survey Bull. 641, pp. 49–61, 1916.

[6] Smith, C. D., The Fort Peck Indian Reservation lignite field, Mont.: U. S. Geol. Survey Bull. 381, pp. 40–59, 1910.

[7] Calhoun, F. H. H., The Montana lobe of the Keewatin ice sheet: U. S. Geol. Survey Prof. Paper 50, 1906.



UNTIES, MONT.

○ Oil well in process of drilling

BASE MAP.

The Bowdoin dome is included in Tps. 30 to 35 N., Rs. 30 to 36 E. Its southern part has been mapped topographically by the United States Geological Survey, and the approximate altitude of all points in this part can be found by consulting the Bowdoin, Saco, and Hinsdale sheets. The only reliable maps of the northern part are based on the township plats of the General Land Office. Many of the townships have been surveyed so recently that their plats are not yet available. Altitudes and topography along the international boundary are given on the sheet prepared by the International Boundary Commission, and the Geological Survey's topographic map of the Cherry Ridge quadrangle, 30 miles west of the Bowdoin dome, shows the altitude of the headwaters of some of the streams that flow into Milk River within the dome. The accompanying base map (Pl. XVI) is compiled from the Bowdoin, Saco, and Hinsdale sheets, the township plats, and the field notes made in 1916 by members of the Geological Survey party.

SURFACE FEATURES.

Much of the area lies in the broad valley of Milk River, which here coincides with the preglacial valley of the Missouri.[1] Its central part is covered by the alluvium of the old Missouri River and by glacial drift from a few feet to more than 100 feet thick. Milk River, Beaver Creek, Whitewater Creek, and Lake Bowdoin are all superposed on this glacial drift and thus have failed to expose the underlying rocks in their valleys. At Malta Milk River is about 2,257 feet above the sea, and at the Vandalia dam it is 2,120 feet—a fall of approximately 4 feet to the mile in a straight line. Beaver Creek enters this area from the south and falls even less than Milk River. Whitewater Creek, entering from the north, probably has a fall of about 10 feet to the mile from the international boundary.

Much of the area is included in the Milk River reclamation project and is owned by private individuals. A great deal of the valley land is on the flood plains and first benches of various streams and has a gumbo soil, but it can be made to yield good crops of blue joint and alfalfa by the use of water. Above the bottoms there are large areas of comparatively level land covered with glacial drift which are too high to be irrigated but which produce good crops of grain by dry-farming methods. North and south of the valley are highlands or benches that rise to elevations of 200 to 500 feet above the valley floor. Between these higher lands and the bottom of the valley are steep slopes on which the bedrock is exposed in many places and some badlands have been formed. The dome structure has been ascertained from these exposures bordering the valley, for within the valley itself bedrock can not be seen.

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[1] Calhoun, F. H. H., The Montana lobe of the Keewatin ice sheet: U. S. Geol. Survey Prof. Paper 50, pp. 45, 46, 1906.

STRATIGRAPHY.

GENERAL SECTION.

The sedimentary rocks in northeastern Montana range in age from Cambrian to Recent, but only the Upper Cretaceous Claggett shale, Judith River formation, and Bearpaw shale, and some of the more recent surficial deposits are exposed in the immediate vicinity of the Bowdoin dome. The information regarding the rocks below the Claggett shale was obtained from observations in the Little Rocky Mountains, about 50 miles to the southwest; that regarding the Claggett and higher formations was obtained from a study of the outcrops around the dome itself. The time spent in the Little Rockies was too short to enable the geologists to determine very definitely the thickness and character of the formations that may be the source and receptacle of oil and gas. The relations of the strata above the Madison limestone are determined from only one set of measurements made on the east side of the mountains, and the determinations may be in error because of changes in dip or unrecognized faults. Owing to the poor exposure of bedrock in parts of this section it is possible that sandstones are present which were not recognized as such. The results of the measurement east of the Little Rocky Mountains and observations around the Bowdoin dome are shown in the following table:

General section of the rocks of the Bowdoin dome, Montana.

System.	Series.	Group.	Formation.	Thickness (feet).	Character.
Quaternary.	Recent.				Silts in the flood plains of streams.
	Pleistocene.				Scattered crystalline boulders; glacial moraines.
					Silt, sand, and gravel deposited along the old channels of the Missouri, Musselshell, and other streams before the end of the glacial epoch.
					Gravel interstratified with yellowish silt at an altitude of 300 feet above Milk River valley. May possibly be late Pliocene.
Cretaceous.	Upper Cretaceous.	Montana.	Bearpaw shale	800-1,000	Dark-gray shale; forms gumbo soil.
			Judith River formation.	400	Light-gray clay and irregular beds of gray and brown sandstone.
			Claggett shale.	750	Dark-gray shale; forms gumbo soil. About 500 feet exposed in Bowdoin dome.
			Eagle(?) sandstone.	100±	Light-gray sandstone; forms a low ridge; contains limestone concretions in its upper part.
		Colorado.		875	Bluish-gray to black shale; contains limestone concretions and marine fossils.
				60±	Light-gray sandstone, capped by a thin limestone containing numerous gastropods.
				485±	Bluish-gray to black shale.
			Mowry shale.	100±	Platy shale or sandstone, which is in places dark-colored but weathers white; contains numerous fish scales; yields traces of oil by distillation.
	Lower Cretaceous.		Kootenai(?) formation.	825±	Mainly shale but includes some poorly defined sandstone. In lower part red and purple shales were noted. A bed of fresh-water sandstone and carbonaceous shale with fragments of woody stems near the base.
Jurassic.	Upper Jurassic.		Ellis formation.	200±	Massive white and yellow sandstone.
				200±	Shale containing *Belemnites*.
Carboniferous.	Mississippian.		Madison limestone.		Massive limestone.

MADISON LIMESTONE.

The Madison limestone is the most striking formation surrounding the Little Rockies. It is the encircling girdle of the mountains in which the picturesque canyons of the streams are cut. Seen from the east these rocks appear like a great horizontal stratum, but on closer examination they are found to be turned up at high angles, and in the small outliers they are continuous over the tops of the hills. The rocks surrounding the Black Hills show a similar relation, and the Little Rocky Mountains have been described as being a miniature reproduction of the Black Hills. The Madison limestone is several hundred feet thick. It is fossiliferous throughout, and from the collections made G. H. Girty has identified at least 22 species and has determined the formation as identical with the Madison limestone of Yellowstone Park and other localities in Montana. It is of early Mississippian (lower Carboniferous) age, and in this area is a massive limestone.

ELLIS FORMATION.

Overlying the Madison limestone is a formation composed of shale and shaly and sandy limestones in its lower part and sandstone and shale in its upper part, and having a total thickness of about 500 feet. In its lower part it carries numerous specimens of *Belemnites* and *Gryphaea*. The detail of this part of the formation is as follows:

Section of lower part of the Ellis formation in the Bowdoin dome, Mont.

	Feet.
Shale with interbedded sandstone and limestone, containing gypsum and carrying abundant fossils	100±
Limestone, thin-bedded, shaly, and calcareous shale carrying fossils	200±

The fauna collected has been examined by T. W. Stanton, who reports that it is Jurassic and similar to that of the Ellis of Yellowstone Park and that of the Sundance formation of the Black Hills. As the Madison limestone is of Mississippian age, there is necessarily an unconformity between it and the Ellis, but the field work was not sufficiently detailed to make its recognition possible.

The upper part of the Ellis consists mainly of light-colored sandstone. The detail of the section as seen at one locality is as follows:

Section of the sandstone in the upper part of the Ellis formation in the Bowdoin dome, Mont.

	Feet.
Sandstone, massive, white, cross-bedded	50±
Shale, variegated	50±
Sandstone, yellowish, thin bedded	100±

KOOTENAI (?) FORMATION.

Variegated shale interbedded with yellow and brown sandstones, not well exposed in any part of the area examined, overlies the Ellis. The shale may be blue, green, red, or gray in places. The thickness given in the table (825 feet) was determined by one measurement and is only approximate. From 100 to 200 feet above the massive sandstone of the Ellis there is in one exposure a carbonaceous sandstone or sandy shale containing woody fragments and poorly preserved plant stems. In an exposure several miles away a conglomerate bed 5 feet thick was noted, but no measurement was made and its exact place in the column can not be stated. This formation is thought to be equivalent to the Kootenai (Lower Cretaceous) of other parts of Montana, though it may also include a representative of the Morrison formation.

MOWRY SHALE.

Above the Kootenai (?) formation a very well marked siliceous shale has been recognized at several localities and is the highest formation described by Weed and Pirsson in their paper on the geology of the Little Rockies. When freshly broken it is dark brown or black, but on weathering it becomes light colored and breaks into porcelain-like débris. It is characterized by the presence of fish scales, some of which can be found on nearly every piece examined, and in some places the trails of small marine animals were also found. Many reports of geologists working in Montana and Wyoming mention a shaly member containing fish scales and place it in the lower part of the Colorado group as the Mowry shale, with which this formation is correlated. Its outcrop around the Little Rocky Mountains is distinguished by a low ridge covered with small pines. The formation, however, may have a much more important relation to the Bowdoin dome than merely as a horizon marker—that is, it is thought to be a shale from which oil may be obtained by distillation. A small fragment of the shale was tested by distillation, and although only a slight indication of oil was obtained it seems almost certain that the formation would yield some oil if properly sampled and tested. The thickness of the formation is about 100 feet.

COLORADO GROUP ABOVE THE MOWRY SHALE.

The part of the Colorado group above the Mowry consists of three formations to which it is not thought advisable to apply any of the formation names used elsewhere in Montana without further field examination. Their total thickness is about 1,260 feet and their detail is as follows:

Above the Mowry shale there is about 325 feet of dark-blue shale, which differs slightly in color from the dark-gray gumbo shale higher in the section. The exposures seen are not continuous, and little can be said of the detail of this part of the section.

Above the blue shale is sandstone capped by a foot or more of impure limestone containing fossil gastropods and pelecypods, which have been identified by T. W. Stanton as belonging to the Benton shale. The stratigraphic position of this sandstone above the Mowry shale is almost identical with that of the Frontier formation of Wyoming and southern Montana. The thickness of the sandstone could only be estimated, and is given in the table as about 60 feet. The sandstone was seen at three localities, where it formed a low ridge. If this sandstone is continuous to the northeast as far as the Bowdoin dome it should form a good reservoir for oil or gas, and it should be reached by the drill before the attempt to find oil in this dome is abandoned.

Above the sandstone is a great thickness of bluish-gray to black shale, much of which is covered and concealed. The shale may include some sandstone or sandy phases that were not seen during the examination. The total thickness of the shale is about 875 feet. It is known to contain *Baculites*, a few specimens of which were collected from concretions.

EAGLE (?) SANDSTONE.

The Eagle (?) sandstone, which lies above the shale last described, is marked by a ridge about 30 feet above the surrounding country. The top of the ridge is covered with large limestone concretions, below which sandstone shows in some places. One imperfect fossil was found in this sandstone, but it is probably not determinable. The same sandstone was seen at a locality about 3 miles southeast of the point where the section was measured, and although it was not closely studied it was thought to be about 100 feet thick. This sandstone is about 750 feet below the base of the Judith River formation, and if it is the Eagle sandstone it proves that the overlying formation varies a great deal in thickness, for the Eagle sandstone is described by Stebinger[1] as being 350 to 500 feet below the base of the Judith River. In the area studied by Stebinger it consists of gray shale and sandstone in its upper part and white to buff massive sandstone in its lower part and is from 250 to 400 feet thick. This sandstone, if it extends as far to the northeast as the Bowdoin dome, is of importance in that it may contain oil or gas. The gas that has been found in the Bowdoin dome probably comes from the Eagle (?) sandstone, for it is estimated to be about 850 feet below the base of the Judith River formation. In the Porcupine dome,[1] south of this region, between Missouri and Yellowstone rivers, the Eagle sandstone is lacking, being represented by shale.

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[1] Stebinger, Eugene, Possibilities of oil and gas in north-central Montana: U. S. Geol. Survey Bull. 641, p. 53, 1916.

CLAGGETT SHALE.

The Claggett shale, which overlies the Eagle (?) sandstone, is, by the single measurement made east of the Little Rocky Mountains, 750 feet thick. In the region investigated by Stebinger it is from 350 to 500 feet thick. It consists of dark-gray shale, containing marine fossils and carries a great deal of gypsum, concretions of aragonite, and calcite. Much of the aragonite shows cone-in-cone structure. The driller of a well in the Claggett shale reported passing through 22 inches of very hard rock, and it is probable that he encountered one of these hard concretions. About 400 feet of this shale is exposed in the center of the Bowdoin dome. Exposures along Milk River on the west side of the dome present the following relations of the Claggett to the overlying Judith River formation:

Contact of Judith River and Claggett formations west of the Bowdoin dome, Mont.

	Feet.
Typical Judith River formation:	
Shale resembling the Claggett	50±
Sandstone like the Judith River but containing marine fossils	20±
Typical Claggett shale containing many *Baculites*.	

North of the Bowdoin dome the section is about as follows:

Contact of Judith River and Claggett formations north of the Bowdoin dome, Mont.

	Feet.
Typical Judith River formation: Shale containing fossils similar to those in the marine sandstone	50±
Typical Claggett shale.	

On the south and east sides of the Bowdoin dome the marine beds that resemble the Judith River are lacking, or at least were not found. The upper part of the Claggett consists of brownish shale without *Baculites* and with little gypsum and aragonite.

JUDITH RIVER FORMATION.

Above the Claggett lies the Judith River formation, which is estimated, from several imperfect measurements, to be from 400 to 425 feet thick. The outcrop of the Judith River surrounds the Bowdoin dome and marks its area, standing out as a light-colored formation in the hills on all sides. This formation consists of hard, brown sandstone; soft, friable, light-colored sandstone; and light-gray shale; but at no point in the formation were any beds found that could be traced far enough to mark definite horizons. In describing this formation Stanton and Hatcher[1] say:

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[1] Bowen, C. F., Possibilities of oil in the Porcupine dome, Rosebud County, Mont.: U. S. Geol. Survey Bull. 621, p. 68, 1915.

> A detailed section taken at any point is of little value, since a similar section made at a distance of only a mile or two would give a quite different sequence of the alternating strata of sandstones and shales.

Some of the details of this formation may be seen from two sections made in its upper part on the east side of Rock Creek, as follows:

Section of Judith River formation on east canyon wall of Rock Creek, in sec. 20, T. 34 N., R. 36 E.

	Ft.	in.
Bearpaw shale.		
Sandstone, massive, grayish, with iron concretions scattered or in beds; weathers yellowish; some red bands; cross-bedded	32	0
Shale, brown, in places approaching lignite	2	0
Sandstone, soft, yellowish gray, and gray shale	23	0
Lignite		6
Shale, brown	1	0
Shale, gray	4	0
Shale, dark, carbonaceous		6
Shale, gray, and sandstone	5	0
Lignite		4
Shale, brown		8
Shale, gray	6	0
Shale, brown	3	0
Sandstone, soft, with iron concretions	1	0
Shale, sandy, brown	2	0
Sandstone, soft, gray	6	0
Shale, gray, clay	4	0
Shale, brown	3	0
Sandstone, soft, gray, and sandy shale	9	0
Sandstone; concretion bed	1	0
Shale, soft, sandy, gray	5	0
Sandstone; iron-concretion bed	1	0
Shale, blue and gray	4	0
Concretion	1	0
Shale, gray	4	0
Shale, brown	2	0
Sandstone, soft, gray and yellow	17	0
Sandstone, massive; weathers brown, arkosic (containing much feldspathic and ferromagnesian material); forms conspicuous ledges	7	0
Sandstone, soft, gray; some shale	20	0
Base not exposed.		
	165	0

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[1] Stanton, T. W., and Hatcher, J. B., Geology and paleontology of the Judith River U. S. Geol. Survey Bull. 257, p. 34, 1905.

Section of Judith River formation in east canyon wall of Rock Creek, near line between sec. 32, T. 34 N., R. 36 E., and sec. 4, T. 33 N., R. 36 E.

	Ft.	in.
Glacial gravel.		
Sandstone, massive, gray; weathers yellow or reddish; some thin beds; cross-bedded	47	0
Shale, gray	6	0
Sandstone, soft, gray	2	0
Shale, gray	4	0
Shale, brown	3	0
Shale, gray	2	0
Shale, brown	1	0
Sandstone, soft, gray	5	0
Shale, brown, with 8 inches of lignite	2	0
Shale, gray	5	0
Shale, brown	6	0
Shale, blue	2	0
Sandstone, soft	9	0
Shale, brown	1	6
Sandstone, soft, gray	3	0
Shale, blue-gray	5	0
Concretions		6
Sandstone, soft, massive, gray	18	0
Shale, brown		8
Lignite		4
Shale, brown	5	0
Shale, blue-gray	12	0
Shale, brown	1	0
Shale, sandy	6	0
Sandstone concretion	1	0
Shale, gray	10	0
Sandstone, soft, gray	13	0
Shale, dark	3	0
Sandstone, soft, gray, and sandy shale	14	0
Shale, brown	2	0
Sandstone, massive, soft, gray or yellowish, weathering yellowish; certain beds weather out as massive reddish layers or as huge concretions; shows some cross-bedding	101±	
Base not exposed.		
	291±	

The base of this formation is not very definitely marked and can not everywhere be separated from the upper part of the Claggett shale. Its contact with the overlying Bearpaw shale is much more definite, although it has been seen in only a few places. The upper part of the formation consists of a massive sandstone in the two sections cited and in the neighborhood of the Little Rocky Mountains. At other points in the field this massive sandstone is not prominent, and in one or two places a small bed of lignite has been mined within a few feet of the top. Stanton and Hatcher report a layer of breccia consisting of shells of *Ostrea subtrigonalis* near the top of the Judith River formation as its most persistent horizon marker, but such beds were not seen at any point in the neighborhood of the Bowdoin dome.

BEARPAW SHALE.

The Bearpaw shale, from 800 to 1,000 feet thick, overlies the Judith River formation. It consists essentially of dark-gray shale which forms a gumbo soil and presents a monotonous and uninteresting landscape. This shale is exposed in many places along escarpments and canyons and forms badlands which lack the variety due to the presence of harder beds. The fossils are all of marine types; *Baculites*, *Inoceramus*, and oysters are very abundant, and occasionally the remains of a gigantic marine saurian are found. Much of the formation contains limy concretions, the lime being in the form of aragonite, showing cone-in-cone structures or appearing like the stumps of large trees. Calcite also is present in many of these concretions. The formation contains more or less gypsum, in the form of plates of selenite or in uncrystallized forms and replacing the calcite of oyster shells.

EARLY PLEISTOCENE OR LATE PLIOCENE GRAVEL.

A formation consisting of more or less cemented gravel interbedded with yellow silt overlies the Judith River and Claggett formations at an altitude of 300 feet above Milk River north of the mouth of Little Cottonwood Creek. Seen from a distance, it can easily be mistaken for the Judith River formation. A single fossil tooth was collected from this material and submitted to Dr. J. W. Gidley, of the National Museum, who identified it as a horse tooth resembling those of the living species.

PLEISTOCENE ALLUVIUM AND GLACIAL DRIFT.

The gravels and silts brought down by Missouri River when it occupied the present valley of Milk River, before the invading ice had forced it to flow through the narrow gorge south of the Larb Hills, appear here and there along Milk River, and such deposits are worked as gravel beds near Malta and Lake Bowdoin. They probably have a very wide distribution, but sediments of this kind are generally covered by glacial débris that was brought in by the ice when the Missouri was forced to abandon its old channel. Much of this glacial drift is in the form of boulders strewn over the surface, but in the northern part of the area, especially along Whitewater Creek, the material is very thick and shows the topography of a glacial moraine.

The deposits of alluvium and glacial drift are of considerable importance in the study of the Bowdoin dome, for they very effectively cover and conceal the underlying rocks and render it impossible to observe the center of the dome, about which little can be learned without the aid of the drill.

STRUCTURE.

The structure revealed by the Judith River formation in its outcrop around the valley of Milk River is that of a very broad, flat dome. The dips of the sandstone are so low as not to be detected by the unaided eye and are best recorded in feet to the mile. There is no place around the dome where a dip as high as 1° has been found.

On the northeast, east, and southeast sides of the dome the beds dip eastward for many miles; on the west side there is a westerly dip for about 35 miles to the neighborhood of Cherry Ridge. On the southwest the dips flatten, the top of the Judith River sandstone being about 100 feet above the river at Coberg, 28 miles from Malta, and outcrops of the same formation are reported to occur at intervals for many miles along the railroad. A dip to the south is indicated by the outcrops of the Lance and Fort Union formations near Missouri River. The only place where a dip large enough to be measured by a clinometer was found is in the Bearpaw shale in sec. 36, T. 36 N., R. 36 E., 30 miles northwest of the dome. Here an inclination of 5° northeast was recorded, but though search was made for similar dips in the rocks northwest and southeast of this locality they could not be found. It must be noted that dips in shale alone are difficult to determine, and that many shale beds show small superficial inclinations.

Along the outcrops of the Judith River formation there are large blocks of sandstone which have broken away and slid down the slopes. A notable instance of such slumping is to be seen near the mouth of Cottonwood Creek, where a large block lies on the east side of Milk River and has been tilted so that its bedding is not parallel with that of its original position. Features of this kind are very suggestive of faults, but it is thought that no real faults are present.

The amount of dip can be seen along Milk River between Hinsdale and Tampico. In this distance the fall of the river is so slight as to be negligible and the outcrop of the Judith River formation, about 400 feet thick, is about 10 miles wide. The dip to the east shown here is estimated to be approximately 60 or 61 feet to the mile, which is equivalent to 41′. Along Eagle Creek in T. 33 N., Rs. 36 and 37 E., a dip of 60 feet to the mile to the northeast was determined by survey with a plane table and telescopic alidade. Along Larb Creek the dip to the south is thought to be about 25 feet to the mile and along Beaver Creek there is evidence that the dip to the south is approximately 28 feet to the mile. West of Malta the dip to the southwest is about 27 or 28 feet to the mile, but along Cottonwood Creek, north of Malta, the dip to the west is much higher, probably from 40 to 60 feet to the mile. To the northwest, along Whitewater Creek, the dip is very much lower and probably does not exceed 15 or 20 feet to the mile.

On an ordinary topographic map the contours are drawn at definite intervals to connect points of equal altitude, and by means of them it is possible to show both the approximate altitude and the shape of the surface features. Structure contours[1] similarly show the relative altitude of different points and the shape of some definite stratigraphic unit. They are the best means yet devised for showing on a map the shape of such structural features as domes and synclines.

The structure of the Bowdoin dome is roughly represented in Plate XVI by contours on the base of the Judith River formation. The highest point reached by the uneroded base of the Judith River formation is at about 2,600 feet above sea level. Only the lower contours, from 2,200 to 2,400 feet, can be drawn with any certainty, and the highest contour, 2,700 feet, is wholly conjectural. In examining this map it must be borne in mind that the work done in this field was all of a reconnaissance nature. The southern part of the field had been topographically mapped by the United States Geological Survey, and the outcrops could be located definitely and their altitude determined, but such work has been done at only a few places. In the northern parts no topographic maps have been made. Altitudes along Rock, Frenchman, Whitewater, and Cottonwood creeks have been determined approximately by assuming these creeks to have a uniform fall from points along the international boundary and in the Cherry Ridge quadrangle to their mouths, whose altitude is known.

It must also be borne in mind that in the northern part of the field the outcrops are in many places concealed by thick deposits of glacial drift, which make the work of the geologist more difficult and may render it impossible to determine where the particular formations lie without the aid of a drill. The structure contours on the base of the Judith River formation were first drawn for the areas in which outcrops were available and then continued at the same dip over the areas in which the base of the formation had been eroded or was so concealed as not to be found.

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[1] Structure contours were first used on United States Geological Survey maps by M. R. Campbell in 1898 (Geology of the Big Stone Gap coal field; U. S. Geol. Survey Bull. 111).

In so broad a feature as the Bowdoin dome minor folds that would make parts of the area more favorable than others for the accumulation of oil or gas are to be expected, but the field work has not been sufficiently detailed to discover them if they exist.

One questionable feature of the Bowdoin dome is its flatness and the low dip (less than 1°) of the surrounding rocks. Many folds in the Ohio and Oklahoma oil fields[1] that have dips as low as those recorded in this field carry oil and gas, but such folds have not been found to be oil bearing in the fields on the flanks of the Rocky Mountains. The Glendive anticline, Montana, which carries gas, is marked by dips as high as 10° to 30° on the southwest side and 5° on the northeast.[2] The Salt Creek dome, Wyoming, which yields oil, has dips on the northeast slope of 8° to 10° and on the southwest slope of 15° to 20°.[3] The size of the Bowdoin dome is comparable to that of the Porcupine dome, near Forsyth, Mont., in which no wells have been sunk. The dips are higher in the Porcupine dome, being 1° to 8° on the north and east sides and 1° to 4° on the west side.[4] The structure of the Bowdoin dome differs markedly from that near the gas well at Havre, which is probably due to an upturned fault block of the earth's crust.[5]

APPLICATION OF THE ANTICLINAL THEORY.

The anticlinal theory relating to the accumulation of oil and gas, which in one form or another has been found to account for nearly all the large oil-producing fields in America, requires the presence of an impervious layer, such as shale, overlying beds of more open texture, such as sandstone, and below or within the open-textured beds disseminated oil and gas or beds from which these substances may be derived. The whole of this series of rock must be folded, producing anticlines or domes and synclines or troughs. In saturated rocks oil and gas collect in the anticlines—that is, the high parts—while water seeks the lower level in the synclines. The Bowdoin dome has a moderate anticlinal structure; an impervious layer is supplied by the Claggett shale; and the oil or gas may be concentrated in the Eagle sandstone at a depth of 400 to 800 feet, in the sandstone at a depth of about 1,600 feet, in the Mowry shale at about 2,100 feet, or in some one of the deeper sandstones. The original source of the oil or gas may be the organic matter of the Mowry shale or some of the other shales and limestones below the Mowry.

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[1] Condit, D. D., Structure of the Berea oil sand in the Woodsfield quadrangle, Ohio: U. S. Geol. Survey Bull. 621, pp. 233–249, 1916. Smith, C. D., The Glenn oil and gas pool, Okla.: U. S. Geol. Survey Bull. 541, pp. 34–48, 1914.

[2] Calvert, W. R., Lignite fields of eastern Montana: U. S. Geol. Survey Bull. 471, p. 201, 1912.

[3] Wegemann, C. H., The Salt Creek oil field, Wyo.: U. S. Geol. Survey Bull. 452, p. 54, 1911.

[4] Bowen, C. F., Possibilities of oil in the Porcupine dome, Rosebud County, Mont.: U. S. Geol. Survey Bull. 621, p. 66, 1915.

[5] Stebinger, Eugene, Possibilities of oil and gas in north-central Montana: U. S. Geol. Survey Bull. 641, pp. 69–72, 1916.

INDICATIONS OF PETROLEUM.

The Martin well, drilled about four years ago in sec. 18, T. 31 N., R. 35 E., encountered gas at a depth reported to be about 640 feet. Though no test has been made, the supply is believed sufficient for domestic use in one family. The log of the well follows:

Log of Martin well in sec. 18, T. 31 N., R. 35 E., Mont.

[Furnished by Jack Rowe, driller.]

	Feet.
Gravel, sand, and surface soil	80
Shale with 22 inches of hard rock 140 feet from the top	555
Sandstone containing fish bones and gas	10
Shale	60

There is a 3-inch casing in the top part of the hole. Drilling was discontinued because the apparatus, an ordinary rig used in boring for water, was not suitable for reaching a greater depth. It is said that no attempt to learn the character of the gas by lighting was made until about a year ago, when it was found to be inflammable. Residents near by state that a bubbling noise could be heard about the well. A contrary report is that the gas had not been found at the time operations ceased, but that the well "drilled itself in"[1] subsequently. If this is true, it indicates that the gas is under considerable pressure, but in view of the conflicting reports no definite statement regarding it is warranted. When visited the well was filled with water within about 20 feet of the surface, and it could not be sounded because of trash dropped in from the top or mud forced in from below. Since the field season closed it is reported in a Saco newspaper that the gas from this well is being used in a heating stove. A well 80 feet deep near Vandalia is also reported to have obtained some gas, but as it is entirely in the Judith River formation this discovery is not important.

During the summer of 1916 there was a great deal of excitement in the search for oil and gas in the vicinity of Saco, and several companies were formed to prospect. Arrangements have been made to sink at least three wells within the Bowdoin dome. Two of these are to be north of Bowdoin Lake and a third somewhere north of Milk River, in the vicinity of Whitewater Creek. The Bowdoin Oil & Gas Co. has begun to drill one of these wells in the NE. ¼ SE. ¼ sec. 22, T. 31 N., R. 31 E.

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[1] A technical expression, meaning that gas or oil under pressure forced an opening after the drill was removed.

CONCLUSIONS.

The Bowdoin dome has a structure which if found in Oklahoma or Ohio would be regarded as favorable for the accumulation of oil or gas. The surface is covered by the Claggett shale, below which, in at least four sandstones that can be reached within 3,000 feet, there are chances of finding oil or gas. Of these four the Eagle sandstone yields gas at Havre, Mont., and probably it may yield gas in this field. The Frontier formation carries the most productive oil pools in Wyoming, and the heavy sandstone of the Ellis is capable of holding a great quantity of oil and gas. Samples of the Mowry shale resemble the oil shale (shale from which oil may be obtained by distillation) that has been prospected in Colorado and Utah, and it is thought that this formation may be an original source of petroleum. There are beds of carbonaceous matter in the Kootenai (?) rocks which, perhaps, correspond to the coal beds mined in the neighborhood of Great Falls. These beds may be a source of oil or gas. Below the Kootenai (?) there is a great thickness of shale, the Ellis, which may be another source.

In the writer's opinion the most favorable place to drill is in the highest part of the dome, which, as indicated by the structure contours, is near the northwest corner of T. 32 N., R. 33 E.

At the present time nothing can be predicted with certainty regarding the field. The structure, the positions of possible sources of petroleum, and the discovery of a small flow of gas certainly warrant a test. Whether or not commercial quantities of oil or gas exist must be left for the driller to discover, and will be ascertained in the near future if the arrangements that have been made are carried out.

THE CORSICANA OIL AND GAS FIELD, TEXAS.

By George C. Matson and Oliver B. Hopkins.

INTRODUCTION.

The Corsicana oil and gas field, in Navarro County, Tex., extends from Corsicana eastward to Powell and from the vicinity of Angus northward to Chatfield. Productive pools having an aggregate area of nearly 50 square miles have been developed in a field that measures 20 miles from north to south and 10 miles from east to west. Oil was first discovered here in the city of Corsicana, which marks the western limit of the productive area, and prospecting has extended the field toward the northeast, east, and southeast from that city. The field may be divided into two parts—the Corsicana district, which lies immediately east of Corsicana and includes the Corsicana, Edens, Angus, Tilton-Havener, and Chatfield pools, and the Powell district, which includes a number of small pools in the area near Powell and Mildred.

The Corsicana oil and gas field is 30 miles north of the Mexia-Groesbeck gas field, 115 miles north of the Thrall oil field, and 160 miles west of the De Soto-Red River and Caddo oil and gas fields. (See Pl. XVII.)

Although the Corsicana field has been productive for more than 20 years, little has been written concerning the geologic conditions under which oil and gas occur there, the age of the productive beds, the number and relative position of the productive sands, and the structural conditions under which these commercial pools of oil and gas have accumulated. The important references to the literature on this field are given below.

Miller, T. D., The recently developed oil field of Texas; Eng. and Min. Jour., June 18, 1898, pp. 734–735.

Oliphant, F. H., U. S. Geol. Survey Nineteenth Ann. Rept., pt. 6, continued, pp. 102–105, 1898.

Phillips, W. B., Texas petroleum: Texas Univ. Min. Survey Bull. 1, pp. 6, 36–42, 1900.

Oliphant, F. H., Petroleum: U. S. Geol. Survey Mineral Resources, 1900, pp. 573–579, 1901.

Adams, G. I., Oil and gas fields of the Upper Cretaceous and Tertiary formations of the western Gulf coast: U. S. Geol. Survey Bull. 184, pp. 54–55, 1901.

Harris, G. D., Oil and gas in Louisiana: U. S. Geol. Survey Bull. 429, pp. 31, 34, 1910.

The purpose of this report is to give a more complete account of the history, production, and geology of this field than has yet been given, especially in regard to the types of structure present and the age and relations of the different sands. Although it was hoped that the study of the region might lead to the location of promising areas for prospecting, this was not the primary object of the work, for the field has been extensively drilled during the last 20 years. Information obtained from the study of this field should be applicable to other areas in the same general region where the geologic conditions are similar.

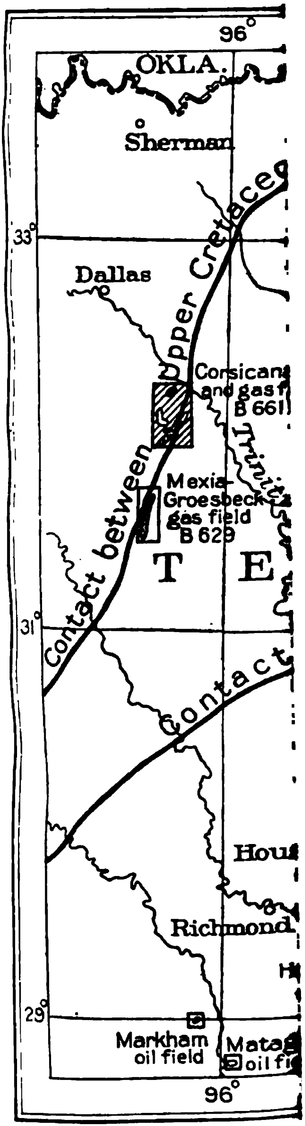
The oil and gas in the Corsicana field are obtained from the upper part of the Upper Cretaceous, the light oil and the gas in the Corsicana oil pool and in the Chatfield and Edens gas pools probably coming from the Taylor marl and the heavy oil and the gas in the other pools from the Navarro formation. The relation of the oil and gas to the geologic structure varies from place to place but is closest where there are well-developed anticlines, such as occur in some parts of the field that yield heavy oil. The distribution of oil and gas is also influenced by variations in the porosity of the sand, though these variations are not as numerous as in the deep oil sand of northwestern Louisiana, and some pools several square miles in area have contained very few unsuccessful wells. The field reached its period of maximum production in 1906, when more than 1,000,000 barrels of oil was produced. There appears to be some possibility of extending the field by the discovery of new pools, but probably the best chance for increasing the production lies in the possibility of the discovery of deeper producing sands, especially in the heavy-oil pools of the Powell district and beneath the gas sand of the Chatfield pool.

ACKNOWLEDGMENTS.

In the absence of sufficient exposures of recognizable beds of rock it was necessary to rely on well logs for a determination of the structure of the field. Partial records of about 725 of the several thousand wells drilled in this field, showing principally the depths to the oil sands, were supplied by the Corsicana Petroleum Co., the Marnet Oil Co., the Houston Oil Co., Mr. C. L. Witherspoon, and Mr. W. G. Baker. Special acknowledgments are due to Superintendent Faulkner and Manager Whitehill, of the Corsicana Petroleum Co.; to Mr. C. L. Witherspoon; and to Mr. A. V. Partaine, of the Marnet Oil Co.

During the month spent in the field the junior author was assisted by Mr. R. P. McClelland, of Corsicana, of whose services he desires to express his appreciation.

U. S. GEOLOGICAL SURVEY



INDEX M

HISTORY.

The oil industry in Texas may be considered to date from 1895, when the first successful well was drilled in the Corsicana field. Before that year the maximum annual production of oil in Texas had not exceeded 60 barrels. The Corsicana field yielded almost the total production of the State from 1896 until the discovery of the Beaumont field in 1901.

Although the discovery of oil in the Corsicana field is credited to Maj. Alexander Beaton,[1] interest in the possibilities of the region was quickened by the finding of oil in a well that was being drilled by the city of Corsicana in the same year, in search of an additional municipal water supply. The oil-bearing stratum, which was reached at 1,027 feet, was cased off, and the well was deepened until a good flow of warm water was obtained at 2,470 feet. The seepage of oil, which found its way to the surface around the casing, aroused the interest of the citizens, who organized a company to test the area. The first well, drilled near the center of Corsicana in 1895, was successful and produced 2½ barrels a day.

The development of that part of the field, which is known as the Corsicana pool, was relatively rapid, and the productive area was extended to the east, northeast, and southeast. In May, 1896, a well that made 22 barrels of oil in the first 24 hours demonstrated the possibilities of this field and stimulated drilling. By the end of 1899 642 wells had been drilled, of which 511 were oil wells, 13 gas wells, and 118 dry holes. The oil from this field was first marketed in 1897, and a refinery was built near Corsicana in the spring of 1898 by J. S. Cullinan. At that time there were 62 wells in the field, producing an average reported yield of 14 barrels a day. The production of this pool, which furnishes the light oil of the Corsicana field, increased until the maximum yearly output of 763,424 barrels was reached in 1901.

In the spring of 1900 oil was discovered 5 miles due east of Corsicana and also at Powell, in the area now known as the Powell district, which produces the heavy oil of the field. Oil was found here at a shallower depth than near Corsicana, and this area was soon extensively prospected. The yearly production of the Powell district increased from little more than 6,000 barrels in 1900 to the maximum of 673,221 barrels in 1906.

Not only the oil industry but the gas industry of Texas may be considered to have originated in the Corsicana field. In 1900, when the yearly production of natural gas in this State was valued at \$20,000,[2] all the gas was taken from the wells in the Corsicana field.

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[1] Phillips, W. B., Texas petroleum: Texas Univ. Min. Survey Bull. 1, p. 6, 1900.

[2] U. S. Geol. Survey Mineral Resources, 1900, p. 050, 1901.

This field continued to yield almost the entire production of Texas until 1909, when the gas fields of Clay County were developed. Gas from the Corsicana field supplied the city of Corsicana until 1913, when the Mexia-Groesbeck field became productive and gas from it was piped to Corsicana. The pumping in the Corsicana oil field has been done for many years chiefly by gas engines, which utilize the casing-head gas obtained from the wells while they are being pumped.

The small gas field south of Chatfield was opened in 1905, and most of the wells were drilled during that and the following years. The wells yielded only a short time; by 1911 the casings had been pulled and all the wells abandoned.

SURFACE FEATURES.

The Corsicana oil field lies along the eastern margin of the Black Prairie,[1] a plain that slopes gently coastward and is covered by a black calcareous clay soil, from which it derives its name. Near Corsicana the altitude of this plain is approximately 450 feet above sea level, and into it the main streams have cut broad, shallow valleys, which have an altitude of about 320 feet. Between the valleys and the plain above there are a number of terraces, which are separated from one another by low, rounded slopes. Near the eastern edge of the field the dark plastic clay gives place to sandy soil, which characterizes the area to the east. Near the western edge of the field a narrow outcrop of sandy beds gives rise to a more angular surface form than is generally present in the Black Prairie region. The soil in this sandy belt is favorable to the growth of scrubby oaks, which further distinguish it from the surrounding almost treeless country.

GEOLOGY.

STRATIGRAPHY.

GENERALIZED SECTION.

The accompanying table (p. 215) contains a list of the formations into which the strata that crop out in the Corsicana field and underlie it at moderate depths have been divided. The table and the diagram in Plate XIX show the order in which the formations are encountered in well drilling and the character and approximate thickness of the beds that compose the formations.

The Navarro and Midway formations crop out in the Corsicana field; the underlying formations are exposed farther west and dip

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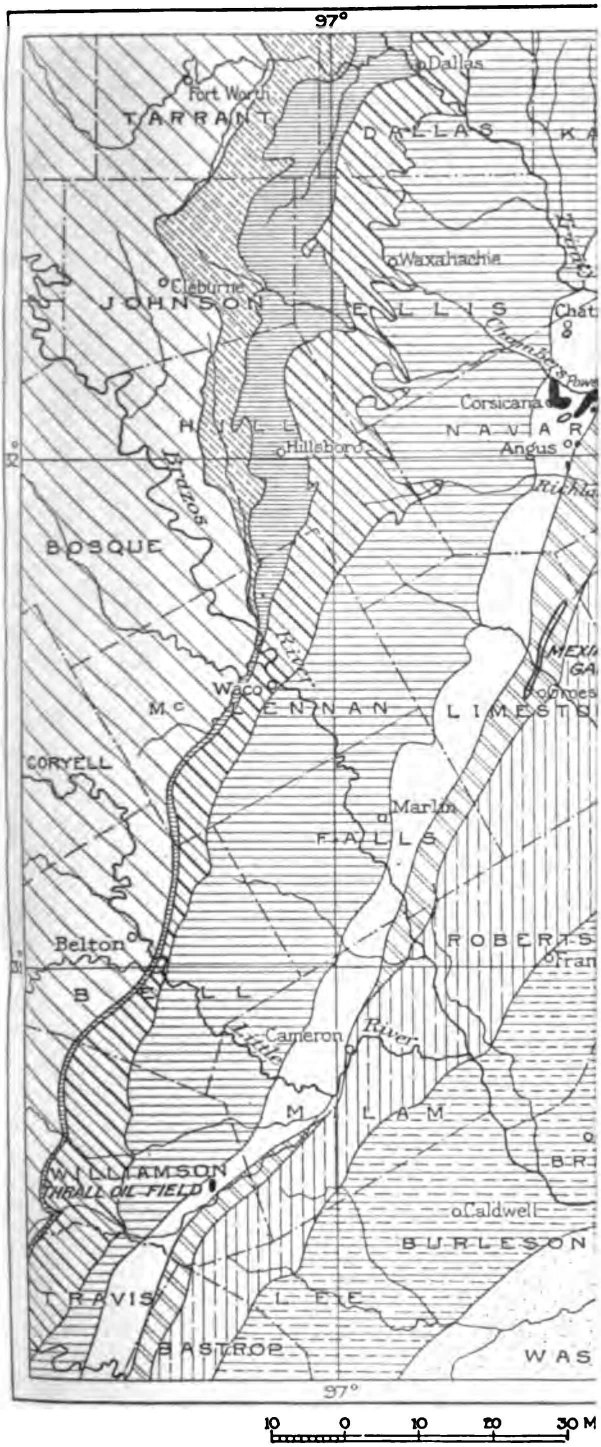
[1] Hill, R. T., Geography and geology of the Black and Grand prairies, Tex.: U. S. Geol. Survey, Twenty-first Ann. Rept., pt. 7, pp. 65–69, 1901.



SKETCH MAP SHOWING THE LOCATION OF THE
GAS FIELD, TEX., AND OTHER PRODUCTIVE FIEL
TOGETHER WITH AN OUTLINE OF THE AREA
REGION.

under this area. Within this field the deep wells drilled for water have reached the Woodbine sand. Oil and gas occur in the Taylor and Navarro formations, and warm, slightly saline water occurs in the Woodbine.

Generalized section of formations in the Corsicana oil and gas field, Texas.[a]

System.	Series.	Group.	Formation.	Thickness (feet).	Character.
Quaternary.	Recent.				Alluvial deposits along streams.
	Pleistocene.				Terrace deposits.
Tertiary.	Eocene.		Midway formation.	250-500	Micaceous sandy clays, fine argillaceous sands, and limestone concretions.
Cretaceous.	Gulf (Upper Cretaceous).		Navarro formation.	1,800-2,000	Light to dark gray calcareous clay, sandy clay, and fine lenticular beds of sand.
			Taylor marl.		Massive calcareous clay marl, little or no sand, and glauconite.
			Austin chalk.	400-500	Gray to white chalky limestone containing some hard beds.
			Eagle Ford shale.	300-400	Light to dark colored shale or clay and thinly laminated impure limestone.
			Woodbine sand.	400-450	Sand, sandy lignitic clay, sandstone, ferruginous sand, and clay.
	Comanche (Lower Cretaceous).	Washita.	Denison formation.	150-200	Clay and limestone.
			Fort Worth limestone.	25-75	Alternating beds of limestone and marl.
			Preston formation.	50-100	Calcareous laminated clays and impure limestone.
		Fredericksburg.	Edwards limestone.	300-400	White chalky limestones, variously indurated, and in places fine arenaceous beds.
			Comanche Peak limestone.		
			Walnut clay.	100-200	Calcareous clays and impure marly and chalky limestones.
		Trinity.	Paluxy sand.	125-200	Fine-grained sand and lenticular beds of clay.
			Glen Rose limestone.	300-500	Impure limestone, marl, and calcareous shales.
			Travis Peak sand.	250±	Conglomerate, sand, sandstone, shales, and impure limestones.

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[a] The formations below the Navarro formation crop out west of the Corsicana field and dip under it. The Upper Cretaceous formations have been penetrated by the drill in this field and are known from well records; the Lower Cretaceous formations have not been penetrated by the drill in this field but are known from outcrops and well records west of the field. The data relating to the Lower Cretaceous are taken largely from a report by R. T. Hill (Geography and geology of the Black and Grand prairies, Tex.: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 7, 1901).

The Navarro formation crops out in the western part of the field and the Midway in the eastern part; the contact between them extends from a point about 1½ miles east of Angus northward 2 miles west of Powell. (See sketch map, Pl. XVIII.) As the strata of the Navarro and Midway in this area are similar in composition and appearance, their separation is based primarily upon the fossils they contain.

The accompanying diagram (Pl. XIX) shows the character of the Cretaceous and the lower part of the Tertiary in eastern Texas. The Lower Cretaceous portion of this diagram was compiled from the log of the well at the Southern Methodist University at Dallas; the lower portion of the Upper Cretaceous was compiled from the log of the refinery well at Corsicana; and the upper portion of the Upper Cretaceous and the lower portion of the Tertiary from the log of Focke No. 2 well, in the Mexia-Groesbeck gas field. The Focke No. 2 well reached the sand that is the approximate equivalent of the sands exposed in the creeks near the west edge of Corsicana and the sands that yield the heavy oil in the Powell district.

CRETACEOUS SYSTEM.

COMANCHE SERIES (LOWER CRETACEOUS).

The Lower Cretaceous formations have not been reached in any of the wells in the Corsicana field, and therefore their depth, thickness, and character in this area are imperfectly known. The depths to the Paluxy and Travis Peak sands, as estimated from well drillings in the neighboring area to the west, are 3,400 and 4,100 feet. (See Pl. XIX.) As these formations contain potable water at a number of localities not far distant, it is possible that they do here also and that they do not contain oil and gas, which are usually associated with salt water or brine. The arrangement and character of the Lower Cretaceous formations are shown in the table of geologic formations and in the nearly complete generalized section of the well of the Southern Methodist University, at Dallas (Pl. XIX).

GULF SERIES (UPPER CRETACEOUS).

Woodbine sand.—The Woodbine sand is the lowest formation of the Upper Cretaceous series in northeastern Texas, where it consists of medium to fine grained sand, clay, and in some places beds of lignite and thin beds of hard sandstone. This formation retains its sandy character over a large area in northeastern Texas, and yields much water. In the Caddo field it is thought to be the source of some gas and most of the high-gravity oil.[1] Outside of that field,

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[1] Matson, G. C., The Caddo oil and gas field, Louisiana and Texas: U. S. Geol. Survey Bull. 619, pp. 48–49, 1916.

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which extends a short distance into Texas, no commercial accumulations of oil and gas have been found in it in this State, with the possible exception of a small pool at South Bosque, near Waco.

The deep well at the Corsicana refinery reached the Woodbine sand at 2,381 feet, and after passing through three water-bearing beds was completed in that formation at 2,781 feet. (See Pls. XIX and XX.) The water from this sand is slightly saline, but not a brine such as usually accompanies oil and gas.

Eagle Ford shale.—The Eagle Ford shale overlies the Woodbine sand and in this area consists of gray to dark-colored fine-grained clay and thin layers and, probably, concretions of limestone. The deep well at the refinery in Corsicana penetrated 376 feet of strata that are referable to this formation. In this area it is not believed to be of any economic value except that it serves as an impervious cover which retains the water in the underlying sand.

The Eagle Ford shale contains sand beds, called the Blossom sand member, in its upper part in northwestern Louisiana, southwestern Arkansas, and the adjacent part of Texas. In the Caddo field some oil and gas have been found in these beds.[1] They are not present in the Corsicana area.

Austin chalk.—The Austin chalk is one of the most easily recognized formations of the Cretaceous, both at its outcrop and in well borings, and constitutes a datum from which the position of other formations may be determined. It consists of alternating beds of white to light-gray chalk and marl of different degrees of hardness. Well drillers commonly call it white rock or limestone. As determined from the log of the deep refinery well at Corsicana, the Austin has a thickness of 425 feet.

So far all the oil and gas of the Coastal Plain of northeastern Texas has been found above the Austin chalk, with the exception of that in Marion and Harrison counties, which represent the western part of the Caddo oil and gas field, and that near South Bosque. In northwestern Louisiana, however, the most productive sands are below the Annona chalk, which is regarded as the eastward extension of a part of the Austin.

Taylor marl.—The Taylor marl consists in general of a uniform series of light to dark gray fine-grained, highly calcareous clay or clay marl. In the Corsicana area it contains some beds of fine argillaceous sand and sandy clay but no coarse sand. It is calcareous throughout and contains rounded limestone concretions. The Taylor marl weathers on exposure to the black plastic clay that is characteristic of the Black Prairie.

Lithologically the Taylor marl is not very different from the overlying Navarro formation, but it contains less sand and glauconite.

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[1] Matson, G. C., op. cit., p. 48.

The contact between these formations can not be easily drawn at the surface, and from well records their separation can be made only in the most general way.

The oil in the Corsicana pool is obtained from a sand in the upper part of the Taylor marl. This sand ranges in thickness from a few feet to a maximum of nearly 60 feet, and according to the reports of well drillers it is in general fine grained and is accompanied by numerous thin layers of shale. Another sand in the Taylor, of somewhat similar character, occurs on the Edens League, 3½ miles south-southeast of Corsicana. This sand, which is gas bearing, is apparently lenticular, for it is not recognized in wells near Corsicana. It may be essentially the equivalent of the gas-bearing sand in the vicinity of Chatfield.

The well logs given on pages 219 and 220 show the character of the the strata of portions of the Taylor formation.

Navarro formation.—The Navarro formation consists of gray, greenish-gray, and yellow, nodular, calcareous clay, and sandy clay and fine glauconitic calcareous sand. (See log of the American Well & Prospecting Co.'s well, p. 219.)

The sand beds composing the Nacatoch sand member of the Navarro are well exposed near the western edge of Corsicana and a few miles north of that city. Locally the sand is firmly cemented by lime to form hard, dense calcareous sandstones or irregular-shaped concretions. The sand ranges from medium grained to very fine grained and contains glauconite, which is more abundant in some beds than in others. These sands are considered to be the same as the Nacatoch sand of northwestern Louisiana, which is an extensive gas-bearing formation. The Nacatoch sand is believed to be the gas sand in the Mexia-Groesbeck gas field,[1] as well as the productive sand in the Powell district, which yields the heavy oil of the Corsicana field. No fossils have been obtained from the wells to show that the oil sand in the Powell district is the Nacatoch, but it is known that this sand dips eastward from its outcrop near Corsicana at an angle that would carry it to about the depth of the oil sand near Powell. The productive sands are the shallowest encountered in the wells near Powell, and they are similar in composition and texture to the Nacatoch sand, and these facts, together with the rate of dip, make it seem safe to conclude that they are the same.

The clays of the Navarro, which occur above the sands, are slightly sandy and glauconitic. They contain numerous calcareous concretions, some with septarian form, some with cone in cone structure, and others of hard, dense limestone. The clay is dark blue when fresh and weathers on exposure to greenish yellow, then to dark olive-gray, and finally to the black waxy soil which is present at the surface over the greater part of the outcrop of this formation.

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[1] Matson, G. C., Gas prospects south and southeast of Dallas: U. S. Geol. Survey Bull. 629, pp. 80–81, 1916.

The following logs show the character of the strata that make up the Navarro formation:

Log of well of the American Well & Prospecting Co., lot 1, block 42, Corsicana, Tex.

[Log made from well samples. Below 45 feet samples were taken at intervals of 10 feet.]

			Thickness.	Depth.
			Feet.	*Feet.*
Navarro formation.		Clay, gray, highly calcareous, fine grained, gypsum bearing	35	35
		Clay, marl, light gray, chalky	20	55
		Same as above, with thin yellow layers of chalky limestone	10	65
		Same, medium fine grained, clear quartz and glauconitic, calcareous	10	75
	Nacatoch sand member.	Sand, fine grained, dark gray; contains small amount of glauconite	10	85
		Sand, argillaceous, highly glauconitic, calcareous, fine grained, dark gray; contains marine shells	10	95
		Same as above, very fine grained	10	105
		Sand, fine grained, dark greenish gray, highly glauconitic, cleaner and slighlty coarser grained than above; fossil shells abundant	10	115
		Sand, medium fine, dark greenish gray, highly glauconitic, probably 40 per cent calcareous, coarser than that above	10	125
		Sand, loose, fine grained, greenishgray, glauconitic, clear quartz	60	185
		Sand, dark gray, very fine grained, hard, calcareous, argillaceous, glauconitic	20	205
		Same as above, becoming more clayey	10	215
		Clay, dark gray, sandy, calcareous	10	225
		Same as above but more sandy in places	20	245
		Sand, dark greenish gray, hard, very fine grained, glauconitic, argillaceous	10	255
		Same as above but slightly coarser grained	10	265
		Sand, dark gray, hard, very fine grained, calcareous, argillaceous	20	285
		Clay, sandy, and very fine sand, dark greenish gray, glauconitic, calcareous; fragments of nacreous shells	10	295
		Clay, dark gray, sandy, calcareous	10	305
		Sand, very fine grained, dark gray, calcareous, argillaceous	10	315
		Clay, hard, dark gray, sandy, calcareous	10	325
		Same as above, with some very fine sand; fossil shells	10	335
		Same as above, glauconitic	20	355
		Clay, dark gray, sandy, highly calcareous, glauconitic	20	375
		Same as above, with some very fine sand	10	385
		Clay, dark greenish gray, sandy, highly calcareous; fossil shells	30	415
		Marl, dark gray, clay, with plates of aragonite	10	425
Taylor marl.		Same as above, with some sandy beds	30	455
		Clay and sandy clay, highly calcareous, dark gray, glauconitic	30	485
		Same as above but more glauconitic	40	525
		Clay, gray, highly calcareous, fine grained	10	535
		Clay, gray, calcareous, and sandy clay	30	565
		Same as above, with some highly glauconitic sandy layers	10	575
		Shale, gray to light gray, calcareous; contains little or no sand	90	665
		Same as above; when roasted gives an odor of sulphur but no distillate	125	785
		Shale, light gray, calcareous, with small fragments of bituminous matter which may have got into the sample accidentally	20	805
		Shale, light gray, calcareous; no sand or bituminous matter	50	855
		Same as above, with thin layer of limestone, fragments of shells	20	875
		Shale, light gray, calcareous	20	895
		Shale, light gray, as above, and sand	10	905
		Shale, light gray, calcareous	40	945
		Same as above, with some fine sand	10	955
		Shale, light gray, calcareous, sandy	10	965
		Same as above, with hard pyritic limestone	10	975
		Shale, gray, calcareous, with dark specks of bituminous matter, and hard sandy limestone	20	995
		Shale, light gray, platy, calcareous	20	1,015
		Shale as above, with fine-grained sand	15	1,030
		Same as above, with less sand	5	1,035
		Sand, fine, gray, calcareous in part, loosely cemented, and some shale	5	1,040
		Same as above, with gray sandy shale	5	1,045
		Sand and shale, laminated, gray, calcareous, and fine-grained quartz sand; contains traces of bituminous matter (probably plant remains)	5	1,050

Log of well No. 22 on B. T. Barry farm, 5 miles east of Corsicana, Tex., in Powell district.

[Made from samples taken at intervals of 20 feet. All the strata belong in the Navarro formation; the Nacatoch sand member from 700 to 810 feet.]

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, dark gray, almost black, gritty, and brown limy clay or clayey limestone	20	20
Sand, brown, limy	40	60
Shale, gray and greenish gray when wet	20	80
Shale, soft, gray, micaceous; contains small shells (Foraminifera?)	20	100
Shale, soft, gray, limy	20	120
Shale, hard, gray, with soft limy streaks	20	140
Shale, gray, slightly limy	20	160
Shale or clay, greenish gray, slightly limy	80	240
Shale, soft, gray, slightly limy, sandy	40	280
Shale or clay, dark gray, very limy and slightly gritty	20	300
Same but more calcareous	20	320
Sand or sandy shale, dark gray, highly calcareous, fine grained, argillaceous	20	340
Clay, gray, slightly limy and gritty; contains numerous small fossils	20	360
Same, with streaks of hard calcareous sandstone	20	380
Shale or clay, greenish gray, limy, sandy	60	440
Shale, gray, calcareous, with sandy streaks	20	460
Shale, soft, gray, calcareous, with dark-gray sandy streaks; contains shell fragments.	20	480
Shale or clay, soft, gray, with limy streaks	20	500
Shale, greenish gray, slightly limy, and fine glauconitic sand	20	520
Shale, greenish gray, calcareous; contains marine shells and hard, dense limestone concretions	20	540
Same, more slimy	20	560
Shale, greenish gray, calcareous	60	620
Shale, greenish gray and brownish gray, calcareous and noncalcareous, with some thin pyrite layers	20	640
Shale, greenish gray, calcareous	20	660
Same, fine grained, dense	20	680
Same; contains little or no grit	20	700
Shale, fine grained, calcareous, with some sand layers, very fine grained	20	720
Sand, very fine grained, greenish brown, limy, glauconitic; contains fragments of shells	20	740
Same, containing some sandy shale, highly calcareous and very glauconitic	40	780
Sand, fine grained, but coarser than that above, highly glauconitic, calcareous	30	810

Log of Millican well No. 13, of Corsicana Petroleum Co., 8½ miles southeast of Corsicana, Tex.

[Drilled in April, 1909.]

	Thickness.	Depth.
	Feet.	*Feet.*
Surface soil	35	35
Shale and rocks	637	672
Hard sand; show of oil	4	676
Shale and mud	11	687
Hard sand	5	692
Gumbo and shale	42	734
Oil sand	9	743
Hard shale	10	753
Hard sand; show of oil	3	756
Rock	2	758
Oil sand	9	767
Rock	3	770
Gumbo	22	792
Oil sand	21	813
Mud and shale	22	835
Shale	20	855

TERTIARY SYSTEM.

EOCENE SERIES.

Midway formation.—The lowest formation of the Eocene, the Midway, is at the surface in the eastern part of the Corsicana oil field, but the exposures there are very poor. According to the reports of drillers, it is apparently a marl containing a few thin beds of limestone. It weathers to a black calcareous clay soil that contains a small percentage of sand and is like some of the soils produced by the more sandy phases of the Upper Cretaceous formations. In the southwestern part of Navarro County and in Limestone County some massive beds of gray and yellow limestone occur in the Midway, but apparently they do not extend into the Corsicana field, though they may be represented there by the numerous limestone concretions that are encountered in the wells.

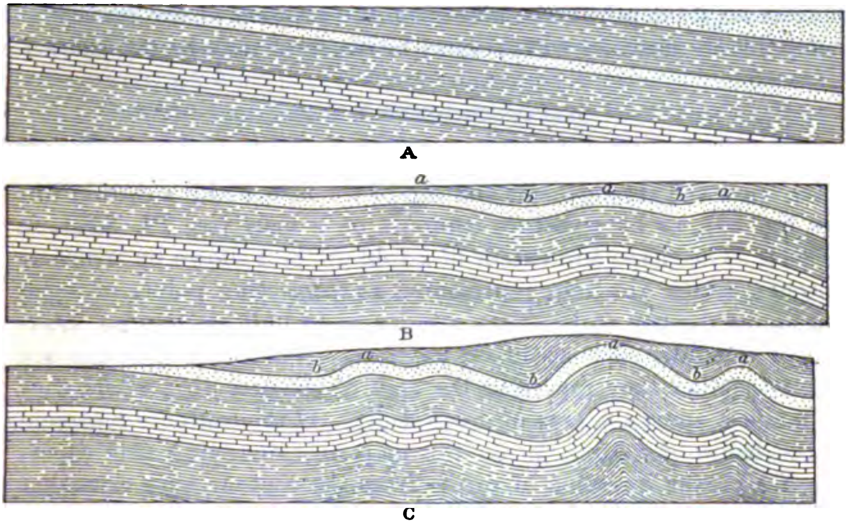

FIGURE 30.—Section showing simple types of structure. A, Sedimentary beds with gentle dip; B, the same beds gently folded; C, the same beds more intensely folded; *a*, anticline; *b*, syncline.

STRUCTURE.

MEANING OF THE TERM.

Most sedimentary rocks, such as clay, shale, limestone, and sandstone, were deposited as horizontal or approximately horizontal layers of sediment and later consolidated into rock. These rock beds, as they are observed to-day, may be only slightly disturbed from their original position or they may be intensely folded and broken, or faulted. The attitude of the beds or their position with reference to a horizontal plane is called structure; the upfolds or upward bends of the beds are called anticlines, and the downfolds synclines. (See fig. 30.) The importance of determining the structure in oil and gas investigations depends upon the fact that oil and gas are commonly associated with anticlines.

Where the beds are highly tilted from their original horizontal position the presence of anticlines or synclines may be determined from observations on the dip or slant of the beds. In an anticline (*a*, fig. 30) the beds dip in opposite directions away from the apex of the fold, called the axis; in a syncline (*b*, fig. 30) the beds dip from opposite sides toward the center or toward the axis. Where the beds are only gently folded it may be necessary to know the altitude at different places of some particular bed, commonly called a key rock, in order to determine the direction of dip and to outline the folds. If the bed whose altitude is to be ascertained is not exposed at the surface it may be encountered in a drill hole, and by subtracting its depth in the hole from the altitude of the surface at that point its position with respect to sea level may be determined.

STRUCTURE-CONTOUR MAP.

Structure may be represented diagrammatically by cross sections which show the arrangement and dip of the beds along a certain line (see fig. 30), or by structure contours on a map (see Pl. XXI, in pocket). The shape and extent of a fold are best shown by structure contours, which are lines represented as connecting points of equal altitude of the key rock. They are drawn to indicate regular intervals of altitude, such as 10 or 100 feet. Where the contours are closest together they represent the area of steepest dip; where they are farthest apart the area of gentlest dip. If the contours represent depths below sea level, as on the map accompanying this report (Pl. XXI), the direction of dip is from the contour with a smaller number to the adjoining one with a larger number. If the dip of the beds is uniform in direction and rate, the structure contours are parallel and uniformly spaced; if the dip is not uniform in direction and amount—in other words, if folds are shown—the contour lines are irregular and variously spaced. The contours on Plate XXI represent the key rocks as they would appear if the overlying formations were removed. The contours bearing the smaller numbers indicate the highest points, and the vertical interval between the contours in 10 feet.

In determining the structure of the Corsicana field the productive sands were used as key rocks—in the Corsicana pool the Corsicana sand,[1] in the Edens and Chatfield pools the gas sand, and in the Powell district one of the beds of the Nacatoch (?) sand, which may not be the same in the different pools. In the Powell district, however, an effort was made to use consistently the upper sand of the Nacatoch (?) beds.

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[1] Not the "Corsicana beds" of Hill, which are the same as the Nacatoch sand, but an unexposed sand 800 feet stratigraphically lower than the Nacatoch.

Level lines were carried over the field to all the wells whose logs were available, about 700 in all. The depth of the oil sand below sea level was determined by subtracting the altitude of the well from the depth to the sand. This gave the depth of the sand below sea level in the wells and furnished the datum on which the contours were drawn. Much difficulty was experienced in interpreting these data. Most of the well records showed only the depths of the sands, and in the absence of some of the sands it was difficult to determine which ones were recorded; the numbers on many of the leases, as well as the names, had been changed one or more times, and it was difficult to connect a well record with the well in which it was obtained; finally, many of the wells had been abandoned and the casings pulled, and it was not possible to get their exact altitudes because their exact locations were not known. However, where the structure is indicated by solid lines the mapping is believed to be correct within 10 feet; where broken lines are used the error is probably not greater than 20 feet, except where a question mark appears on the map.

GENERAL STRUCTURE OF THE FIELD.

The strata in the Corsicana field dip in general to the southeast at a rate of 50 to 100 feet to the mile. The uniformity in direction and amount of dip is interrupted at a number of places by folds, as shown on the accompanying map (Pl. XXI), but none of the folds are continuous over large areas. The greatest dips observed on the folds are at the rate of 560 feet to the mile, and these high dips are confined to small areas. The irregularities in the normal position of the strata seems to have been produced by forces acting in two directions, as the folds trend noticeably in two directions—one approximately parallel to the dip of the rocks and the other at right angles to it. So far as observed, there is no evidence of faulting, or breaking of the rock strata, in this field.

STRUCTURAL FEATURES IN DETAIL.

CORSICANA POOL.

In the Corsicana pool the producing sand has a southeasterly dip of 80 to 100 feet to the mile. Slight variations, both in the direction and amount of dip, appear in different parts of the pool, and toward the north end there is some evidence of a westerly dip. The depth of the productive sand increases from 530 feet below sea level about 4 miles north of Corsicana to about 800 feet below near the old waterworks. The dip of the beds west of the pool is not shown by well records, but surface exposures indicate that it is in the same general direction at a slightly lessened rate. Between Forreston and Corsicana, a distance of 21 miles, the average dip is about 65 feet to the mile, as shown by the altitude of the Austin chalk at these two places, but to judge from the character of the surface exposures within 5 miles of Corsicana the dip is somewhat lower than 65 feet to the mile near the city and therefore it must be greater than the average rate farther west. Local variations in the rate of dip of the sand near the southern boundary of Corsicana may account for the presence of accumulations of gas, though there is some doubt as to the correlation of the gas-bearing sand with the oil sand. If they are the same, there is apparently a low, flat-topped dome at this locality in which only the upper portion of the sand is filled with gas. If the sand had been folded into a sharp dome or anticline a greater thickness of the sand at the apex of the fold would have been filled with gas, and the wells there would have furnished gas for a longer period before they were filled with salt water.

EDENS POOL.

Twenty-five or more wells, many of which produced gas, have been drilled on the Edens League, 3 miles south-southeast of Corsicana. At the time when the study of this field was made all the gas wells on this and adjoining leases, forming the Edens pool, had been abandoned and the casings pulled. The location and altitude of many of the wells could not be ascertained, and consequently it was not possible to contour the gas sand of this pool accurately.

The fragmentary data available indicate that a low northeastward-trending anticline crosses the northern part of Edens League, and that its highest part is in the valley of Elm Creek. Most if not all of the gas wells in this area produced from depths of 630 to 660 feet below sea level.

CHATFIELD POOL.

The structure of the pool south of Chatfield, as outlined from the well records, shows a low, irregular anticline that trends northeast and is 2 miles long and about three-quarters of a mile wide. The dips on its flanks are as much as 2°. The accumulation of gas is in the crest of the anticline and is backed up on all sides by salt water. All the gas wells except one encountered the sand where it is less than 420 feet below sea level, or above the 420-foot contour. One small gas well on the T. B. Roberts property is near the 440-foot contour. So far as known oil was not found in this pool. The wells here were drilled during 1905 or a short time thereafter, and by 1911 all of them had been abandoned and the casings pulled.

MILDRED POOL.

The structure of the pool near Mildred is complex; its principal features consist of a well-defined branching anticline at the north end, a shallow eastward-trending syncline, a low dome or structural terrace, and beds of practically uniform dip at the south end. It is evident that this complex structure was produced by forces acting in two directions, approximately at right angles to each other. The details of the structure of this pool, so far as it has been possible to outline them from the data available, may be best understood from an inspection of Plate XXI.

At the north end of the pool the oil sands dip to the northeast, and most wells reaching the sands at a depth greater than 450 to 460 feet below sea level were "dry." The productive area at the southwest end of the pool is between the 300 and 210 foot contours, which represent the depth of the oil sand below sea level. It is evident that the productive area does not follow the trend of the contour lines and that the accumulation of the oil does not depend alone on the structure. Some wells beyond the western limit of the productive pool encounter sands that yield only traces of oil. This condition may be due to decrease in the porosity of the sand or to the lack of sufficient pressure to cause the oil to flow freely into the wells.

WITHERSPOON-McKIE POOL.

The Witherspoon-McKie pool, southwest of Powell, lies along the crest of a low, flat-topped anticline which extends from the southeastern part of the Witherspoon tract southwestward 1½ miles to the McKie tract. Although extensive drilling has been done in this pool, few well records have been preserved, and it is impossible to outline accurately the details of the fold. The highest part of it is on the south side of Post Oak Creek, a quarter of a mile above its junction with Chambers Creek. The depth to the highest productive sand is 825 to 875 feet, and to the lower sand about 100 feet more. Oil and gas were present only along the crest of the anticline, and water was troublesome over practically the entire pool. Gas was present originally in both the upper and lower sands, but more abundantly in the lower. All the wells at the north end of the pool have been invaded by salt water and abandoned.

CLEMENTS-BUCHANAN POOL.

The accumulation of oil in the Clements-Buchanan pool, northeast of Mildred, is associated with a sharp downward bend of otherwise gently dipping beds. The dip of the beds appears to be locally as much as 560 feet to the mile to the southeast, and the oil occurs in the area of steep dip where the beds are at depths between 395 and 490 feet below sea level. Northwest of the productive area the beds dip to the southeast at a smaller angle, probably less than 180 feet to the mile.

BURKE POOL.

The Burke pool, 1 mile south of Powell, is associated with the most pronounced fold that has been found in the Corsicana field. Only the south end of the fold can be outlined, because the well logs were available only for that part of the pool. As shown on Plate XXI, this fold, which is probably a shortened anticline or dome, has dips of about 185 feet to the mile to the northwest, southwest, and southeast. Oil occurs in the upper part of the fold, where the upper sand is from about 400 to 480 feet below sea level. Where the sand is more than 480 feet below sea level it is generally saturated with brine, although in that area a number of wells have yielded some oil and a few producing wells have been completed.

ANGUS POOL.

The strata in the pool south of Angus dip gently to the east at a fairly uniform rate, and the upper oil sand, which is about 200 feet below sea level in the southwestern part of the pool, lies at a depth of 340 feet or more in the eastern part. The oil is followed up in the eastern part of the pool by salt water, which is practically absent in the western part of the development area, where the beds are higher.

So far as can be determined from the available well records the dip of the beds within the Angus pool is practically normal for this region—that is, to the east or southeast. The oil sand which is contoured in the Angus pool is believed to be the same as that in the Tilton-Havener pool, where it is about 200 feet deeper.

RELATION OF OIL AND GAS TO STRUCTURE.

A review of the discussion of the structure or a study of the structure map of the Corsicana field will show that oil and gas occur in this field under two different structural conditions. They have accumulated along the crests of well-defined anticlines, as in the Burke pool, and also in beds of fairly uniform dip, as in the Corsicana pool. In this field no two of the three sands, the Corsicana, Edens, and Nacatoch, are productive at any one place. This may be due to the fact that the deeper sands have not been reached by the drill in places where production was obtained from the shallower sands; or the productive area in the deep sand may be limited to the Corsicana pool, for there are other factors than structure that control the accumulation of oil and gas, among them the distribution and porosity of the productive sand. If the productive sands were uniform in thickness and porosity over the entire field, in an area where the structure is favorable for the accumulation of oil and gas in one sand, it might be favorable for accumulation in the other sands also. Drilling has shown, however, that the sands of this field are lenticular and vary in porosity and thickness from place to place. The accumulation of oil and gas in some places may be due to the pinching out of the sand, which prevents the oil and gas, backed up by salt water, from migrating farther up the dip. This condition would account for the accumulation of oil in the Corsicana pool, where a portion of the western limit of the pool may also be the western limit of the porous sand that yields the oil. The location of this pool with reference to the structure shows that there is also a structural reason for the accumulation of the oil. The decrease in the rate of dip of the oil sand west of Corsicana would check the migration of fluids, and the low dip would be less favorable for their migration and accumulation than the steeper dip farther east. Low hydrostatic head combined with low gas pressure in thin, fine-grained sands having moderate dips favor a slight migration of the fluids in the direction of the dip and a wide distribution of the oil, such as exists in the Corsicana pool.

The accumulation of oil in the Angus, Tilton-Havener, and Clements-Buchanan pools may be controlled by the same factors as those that control it in the Corsicana pool, but the evidence is not conclusive, and variations in the sand may have been an important controlling factor. The largest gas pools in this field, such as the Edens, Witherspoon-McKie, and Chatfield pools, are associated with anticlinal folds. On the other hand, the most pronounced fold in the area, that associated with the Burke pool, contains much oil but little gas.

OIL AND GAS.

OCCURRENCE.

GEOLOGIC DISTRIBUTION.

In the Gulf Coastal Plain the two important series of petroliferous strata are the Upper Cretaceous and the late Tertiary, which contain oil in different areas and under different structural conditions. The Upper Cretaceous fields, such as those of northwestern Louisiana and the Corsicana, Powell, Mexia-Groesbeck, and Thrall fields of Texas, lie at considerable distances from the coast. The late Tertiary or early Quaternary fields, such as the Jennings, Vinton, Spindletop, and Humble, are near the coast. The Upper Cretaceous beds that yield oil and gas are usually more or less extensively folded, and the areas of production may be several miles across. On the other hand, most of the Tertiary and Quaternary fields occur where there are masses of rock salt that form cores of domes (saline domes) from which the oil-bearing beds dip steeply, and these fields are all small, generally covering not more than a few hundred acres.

The Upper Cretaceous series includes two commercially productive formations—the Woodbine, the most productive oil sand of northwestern Louisiana, and the Nacatoch, the most widely distributed gas sand of the Coastal Plain. In Texas the Woodbine is productive only in the Caddo field, which extends into Marion and Harrison counties, and probably at South Bosque, near Waco. At Corsicana the Woodbine yields water which is only slightly saline, and not such brine as is usually associated with oil and gas. The Nacatoch, on the other hand, supplies gas in all the fields of northwestern Louisiana and in the Mexia-Groesbeck field, Tex.,[1] and oil in some areas in northwestern Louisiana and probably in the Powell district of the Corsicana field, Tex. The Taylor marl, which is productive in the Corsicana district, is not productive, so far as known, at any other locality in Texas except Thrall, where the conditions are unusual.

The productive formations are not the same in the Corsicana and Powell districts. The Taylor marl, which yields light oil in the Corsicana district, dips under the Powell district but has not been exploited there; the Nacatoch sand member of the Navarro formation, which yields heavy oil in the Powell district and which is probably the equivalent of the Nacatoch sand of Louisiana and Arkansas, is not productive in the Corsicana district and crops out a short distance west of it. Plate XX shows the approximate relative positions of the sands of the Corsicana and Powell districts.

CORSICANA DISTRICT.

PRODUCING SANDS.

In the Corsicana district there are at least two productive sands which are believed to belong to the Taylor formation—the Corsicana and Edens sands. (See generalized section, Pl. XX.) The Corsicana sand is the principal producing sand and yields light oil and a small amount of gas at a number of places, particularly toward the north end of the district. The Edens sand formerly yielded gas in a small area 2 miles southeast of Corsicana; it may be the equivalent of the sand which yields gas in the gas pool south of Chatfield. The age of the sand near Angus, which yields light oil similar to tha

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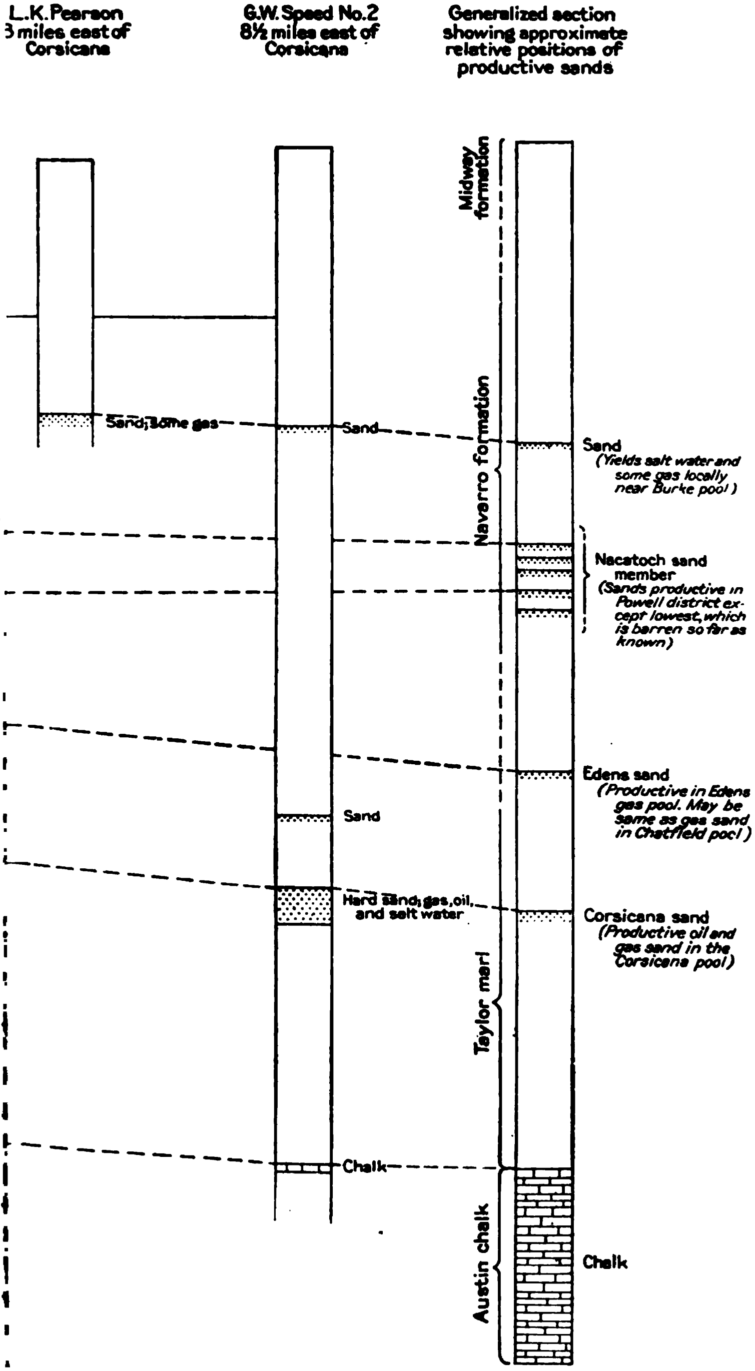
[1] Matson, G. C., Gas prospects south and southeast of Dallas: U. S. Geol. Survey Bul 629, pp. 81–82, 1916.


L.K. Pearson
3 miles east of
Corsicana
G.W. Speed No. 2
8½ miles east of
Corsicana
Generalized section
showing approximate
relative positions of
productive sands
Midway formation
Navarro formation
Taylor marl
Austin chalk
Sand; some gas
Sand
Sand
(Yields salt water and some gas locally near Burke pool)
Nacatoch sand member
(Sands productive in Powell district except lowest, which is barren so far as known)
Edens sand
(Productive in Edens gas pool. May be same as gas sand in Chatfield pool)
Sand
Hard sand; gas, oil, and salt water
Corsicana sand
(Productive oil and gas sand in the Corsicana pool)
Chalk
Chalk

TENTATIVE CORRELATIONS IN THE GENERALIZED

from the Corsicana sand, is not known, although geologic evidence suggests that it belongs to the Nacatoch member of the Navarro formation.

CORSICANA POOL.

The Corsicana sand is 500 to 550 feet above the top of the Austin chalk, about 800 feet below the Nacatoch sand and about 300 feet below the Edens sand. (See Pl. XX.) In the Corsicana pool it ranges from a few feet to 60 feet in thickness and consists of fine-grained sand and sandy shale. It has been described by Oliphant[1] as consisting of almost pure dark-gray quartz sand containing Foraminifera of several kinds, among which are *Rotalia*, *Nomionina*, and *Globigerina*. This sand is fairly persistent in character and thickness over the productive area and is underlain and overlain by impervious, massive plastic clay. It ranges in depth from 800 feet below sea level, or about 1,200 feet below the surface, near the old waterworks, 2 miles southeast of Corsicana, to 530 feet below sea level, or 900 feet below the surface, 4 miles north of the city. (See Pl. XXI, in pocket.) This sand has been productive over the greater part of an area 6 miles long from north to south, 2 miles wide at the south end and half a mile wide at the north end. The upper 10 to 20 feet or more of sand, although it commonly gives a show of oil or gas, is so fine grained that it does not yield its oil as readily as the coarser sand below. The wells are drilled into the sand from 25 to 60 feet and are completed when the flow of oil into the well is sufficient to make pumping profitable, or abandoned when the amount of water is so great in proportion to the oil that pumping is unprofitable.

In the early history of the field some of the wells flowed, owing to the pressure of the gas that was originally present, but for many years all the wells have been pumped. After the wells are completed they are allowed to stand for a day or two, and during that time they fill up from 300 to 800 feet with oil, oil and water, or water. Gas occurs in small areas near the western limit of the pool, where the beds are highest; salt water or brine occurs in small quantities over much of the pool but increases in amount toward its eastern and southeastern limits, where the beds are lower. In general the productivity of the wells depends on the thickness and porosity of the sand; the accumulation of the oil and gas depends on the structure and the distribution and character of the sand. As the yield of oil in the pumping wells declines, the percentage of water increases. The flow into the wells is slow at the present stage of development because of the almost complete absence of gas pressure and the fineness of the productive sand.

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[1] Oliphant, F. H., U. S. Geol. Survey Nineteenth Ann. Rept., pt. 6, continued, p. 102, 1898.

EDENS POOL.

The Edens sand produced considerable gas in the early history of the Edens pool, but the wells were soon exhausted, and all of them have been abandoned and the casings pulled. The principal productive area was on the Edens League, 3 miles southeast of Corsicana. The wells were drilled 10 to 20 feet into the sand and originally showed a rock pressure of 150 to 200 pounds to the square inch.

CHATFIELD POOL.

It is not possible to correlate the gas sand of the Chatfield pool accurately with those near Corsicana, but it is believed that this sand is of Taylor age and approximately the equivalent of the Edens gas sand. It ranges in thickness from 8 to 16 feet and lies about 850 feet below the surface. Approximately 180 feet below it is another sand, which produces large quantities of salt water, and this may be the equivalent of the Corsicana sand. The following well log shows the depths and relations of the sands in this area, although the thickness of the first sand is probably exaggerated:

Log of T. B. Roberts well No. 3 of Houston Oil Co., near Chatfield, Tex.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	1	1
Yellow clay	34	35
Hard bluish sand	48	83
Gravel and white sand	5	88
Brownish shale	293.5	381.5
Black quartz	58.8	440.3
Brownish shale	405.8	846.1
Through sand into shale; good gas pressure	40.8	886.9
Shale	118.1	1,005
More gas sand and better pressure	18.7	1,023.7
Shale	8.3	1,032
Salt-water sand	13	1,045
Shale and bluish mud; abandoned at this depth	139.2	1,184.2

The gas wells here, some four or five in number, were small producers, and the gas was piped to Corsicana for domestic use. Most of these wells were drilled in 1906 and 1907, and all of them were abandoned and the casings pulled before the end of 1911.

ANGUS POOL.

The fragmentary records available suggest that a number of different sands that may belong to the Nacatoch sand are present in the pool near Angus. The sands occur within a vertical interval of about 150 feet, and the wells are completed at depths of 600 to 800 feet. As no complete logs of the wells in this pool are available, the number and relations of the sands can not be determined, and their correlation with the sands of the other pools is uncertain. The light gravity of the oil suggests that they may be the equivalent of the Corsicana sand instead of the Nacatoch sand. Gas is most abundant in the southwestern part of the pool, where the beds are in the highest structural position; water is most abundant in the eastern part of the pool, where the beds are lowest.

Showings of oil have been found in a number of wells between the Angus pool and the town of Angus, among them being wells Nos. 1 and 4 on the property of Latta Bros., which are dripping oil at the present time. Much salt water is reported on this and adjoining leases from what appears to be the upper sand.

A number of gas wells have been drilled northeast of Angus, mostly on the Petty and Birdwell leases, but no records of them have been kept, and it is not known whether the sands here are the equivalent of the Edens or the Nacatoch sand. On the Birdwell lease gas, which was formerly piped to Corsicana, was found at a depth of about 700 feet and a trace of oil at 725 feet.

TILTON-HAVENER POOL.

The oil from the Tilton-Havener pool, east of Angus, may be derived from the equivalent of the highest sand of the Angus pool, although the well data are not sufficient to make the correlation conclusive.

POWELL DISTRICT.

GENERAL FEATURES.

The Powell district includes all the pools in the Corsicana field that produce heavy oil. It is not possible, with the fragmentary records available, to correlate accurately all the sands in this district. The productive sands, which are lenticular and vary in porosity and thickness, are believed to occur within an interval of about 100 feet. In this district usually two or three and exceptionally four productive sands are reported, besides a shallow sand that yields a small amount of gas at a few places, as in the L. K. Pearson and G. W. Speed wells. (See Pl. XX.) The productive oil sands in this district are believed to represent a part of the Nacatoch sand member of the Navarro formation and are grouped under the name Nacatoch sand.

In the productive area these sands lie at depths ranging from 650 feet west of Mildred to 950 feet north of Powell. They are about 800 feet above the Corsicana sand and about 1,300 feet above the Austin chalk. They are overlain and underlain by thick beds of massive, impervious clay or clay marl of marine origin.

The productive sands of the Powell district are separated into individual sand beds by lenses of finer-grained sand and shale. It is doubtful whether any one of the four sands that are reported from some wells is present at every locality where wells have been drilled in the district. In most of the well logs two or three sands are reported, and in many of them only one sand is recognized, a condition that is not uncommon in logs of wells drilled by the rotary process. The following well records show the relative positions of the sands:

Log of W. L. Derden well No. 5 of Marnet Oil Co., 3½ miles east of Corsicana, Tex.

	Thickness.		Depth.	
	Ft.	*in.*	*Ft.*	*in.*
Shale	120	0	120	0
Rock		6	120	6
Shale	250	0	370	6
Rock		6	371	0
Shale	245	0	616	0
Rock	1	6	617	6
First oil sand	26	0	643	6
Shale	7	0	650	6
Sand	28	0	678	6
Mud	2	0	680	6
Sand	6	7	687	1
Rock	1	2	688	3
Good sand	19	0	707	3
Shale	8	0	715	3
Gumbo	3	6	718	9
Rock	2	7	721	4
Sand	14	0	735	4
Shale	7	0	742	4
Sand	9	0	751	4
Shale	2	2	753	6
Gumbo	10	0	763	6
Rock		10	764	4
Sand	18	0	782	4
Rock		6	782	10
Sand	10	0	792	10
Gumbo	7	2	800	0

Log of J. W. Combest well No. 5, 1 mile northeast of Powell, Tex.

	Thickness.		Depth.	
	Ft.	*in.*	*Ft.*	*in.*
Soil	50	0	50	0
Rock		4	50	4
Shale	151	2	201	6
Rock		6	202	0
Shale	311	4	513	4
Sand; show of oil and gas	8	0	521	4
Shale	447	0	968	4
Rock		4	968	8
Oil sand; good show of oil	25	10	994	6
Gumbo	1	0	995	6

Log of C. P. Kerr well No. 6 of Corsicana Petroleum Co., 3 miles east-southeast of Corsicana, Tex.

	Thickness.	Depth.
	Feet.	*Feet.*
Shale and boulders	700	700
Hard sand	6	706
Broken sand	12	718
Shale	33	751
Sand	3	754
Shale and gumbo	34	788
Sand	4	792
Hard shale, gritty	10	802
Sand	18	820
Shale	21	841
Rock	2	843
Shale and mud	7	850

Log of J. W. Millican well No. 10 of Corsicana Petroleum Co., 3 miles east-southeast of Corsicana, Tex.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface clay	30	30
Shale	684	714
Sand and shale	7	721
Hard sand	1	722
Oil sand	8	730
Sand and mud	12	742
Hard sand; trace of oil	4	746
Shale	33	779
Oil sand	18	797
Sand and mud	5	802
Shale	4	806
Hard shale	9	815
Do	½	815½
Oil sand	6½	822
Hard lime rock	4	826
Fine-grained sand	21	847

Log of Bryan T. Barry well No. 15, 4 miles east of Corsicana, Tex.

	Thickness.		Depth.	
	Ft.	*in.*	*Ft.*	*in.*
Soil		6		6
Clay	49	6	50	0
Rock		8	50	8
Shale	14	4	65	0
Rock		4	65	4
Shale	17	8	83	0
Gumbo	4	0	87	0
Shale	13	0	100	0
Rock		6	100	6
Shale	18	6	119	0
Rock	1	2	120	2
Shale	54	10	175	0
Rock, soft	2	0	177	0
Shale	51	0	228	0
Rock		6	228	6
Shale	439	6	668	0
Rock		4	668	4
Shale	51	8	720	0
First sand; show of oil	27	0	747	0
Shale	72	3	819	3
Rock	1	6	820	9
Shale	3	6	824	3
Second sand	15	9	840	0

Produced initially 12 to 15 barrels a day.

The highest of the Nacatoch (?) sands of the Powell district ranges in thickness from 8 to 15 feet or more and usually yields some oil but little water. At some places it yields only a trace or a small amount of oil; at others it is the most productive sand. The second and third sands are less persistent than the others and are not recognized at many places; they are fine grained and yield but little oil or water, except locally. The average interval between the first and second sands is 25 feet, between the second and third 40 feet, and between the first and fourth about 100 feet. The lowest sand is the most productive in the western part of the field, where it probably yields two-thirds of the production of the wells. It also contains much salt water near the southeastern limit of the individual pools. In the small pools in the northeast end of the Powell district, near Powell, it is not possible to determine definitely which of this group of sands is the productive one.

The Corsicana sand probably underlies the Powell district, as it appears to have been found in the G. W. Speed well, 8¼ miles east of Corsicana, beyond the eastern limit of the Powell district. Few wells in the Powell district have reached this sand, and the possibility of obtaining oil from it there has not been determined.

MILDRED POOL.

In some parts of the Mildred pool, which extends from a point a short distance west of Mildred northward across the Cotton Belt Railroad, all the four sands of the Nacatoch (?) are present. Near the south end of the pool all four sands are productive to a different degree and the wells are drilled to the deepest sand; near the north end, on the other hand, the upper sand is more productive, and on the Junior Pipe Line Co.'s leases only a few of the wells are drilled to the deep sand. Most of the wells in this pool, however, are drilled to the deep sand, and as the casings are set at the top of the upper sand the product thus obtained represents the combined yield of all the sands present. This method is possible because most of the water present is in the lowest sand. The water in the lowest sand is troublesome only in the southeastern edge of the pool, as outlined by existing wells. Near the central and western parts of the pool little or no water is present, and many of the wells are drilled below the base of the lowest sand without being injured by the presence of water.

WITHERSPOON-McKIE POOL.

In the Witherspoon-McKie pool the upper and lower sands are productive but not the intermediate ones. The upper sand is interlaminated with shale and yielded oil and some gas when this pool was first drilled. It was developed first, and a number of oil wells were completed in it before the presence of the lower sand was known. The interval between the upper and lower sands, which is approximately 100 feet, has been described as follows:

Partial log of Stone well No. 4, 7 miles east of Corsicana, Tex.

	Thickness.	Depth.
	Feet.	*Feet.*
Top of first sand	....	880
Hard sand; show of oil and gas	15	895
Shale	55	950
Hard rock	2	952
Soft shale interlaminated with sand	28	980
Hard rock	1	981
Sand, bearing oil and water	5	986

Log of Stone well No. 5, 7 miles east of Corsicana, Tex.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay and gravel	60	60
Shale	784	844
Rock	1	845
Sand, with oil and gas	3	848
Shale and sand interbedded; made showing of oil and gas	26	874
Sand and shale interbedded	32	906
Shale and layers of hard rocks	29	935
Sand; oil and some gas	1	936

Four gas wells besides a number of oil wells have been completed in the lower sand. One of the gas wells, which had a reported pressure of 350 pounds to the square inch and a volume of 4,000,000 cubic feet, supplied the city of Corsicana with gas for three years. At present the gas from these wells is not being used, and the gas pressure has decreased so much that the wells would yield little without the installation of compressors. At least one oil well in this sand flowed for a few days as much as 150 to 200 barrels of oil. In this pool only the top of the sand in places where the structural conditions were most favorable was filled with oil and gas; elsewhere the sand carried salt water. Water was troublesome over the entire pool, and many of the wells that were drilled only a few feet into the sand yielded too much water to justify the cost of pumping. All the wells at the north end of the pool have been abandoned.

CLEMENTS-BUCHANAN POOL.

The small oil pool on the Clements and Buchanan leases is believed to be productive from the lower bed of the Nacatoch (?) sand of that area. No complete logs of any of the wells in this area are available, and the partial logs contain no mention of any upper sands;

if such sands are present they were doubtless unproductive. The only gas obtained in this pool is casing-head gas, which is used as a fuel in the gas engine employed in pumping the wells.

BURKE POOL.

All the oil from the Burke pool is derived from one sand, which is probably the upper bed of the Nacatoch (?) sand of the district. No gas wells were developed in the main pool; some gas was found, however, at the north edge of it, but whether in the productive oil sand or a shallower sand is not known. A shallow sand about 200 feet above the oil sand yielded gas on the Pearson lease. The oil sand contains water in troublesome quantities only around the edge of the pool; the wells near the center of the pool yield little or no water The presence of a well-developed fold in this area probably accounts for the fact that the water conditions are different from those in many of the other pools of the field, where water is present in abundance only on the southeast sides of the pools.

COMBEST AND WHITE POOLS.

The productive sand in the Combest and White pools, near Powell, is believed to be the same as that in the Burke pool—that is, the highest of the Nacatoch (?) sands in the Powell district—but the lack of accurate well logs makes a definite correlation impossible. Small pockets of gas under considerable pressure have been found in the Combest pool. One gas well in this pool gave considerable promise, and a pipe line to Corsicana was planned, but before the line could be laid the well was practically exhausted.

COMPOSITION.

OIL.

The accompanying table of analyses shows the general quality of the oil found in the Corsicana and Powell districts. For the purpose of comparison there have been added analyses of the oil from the Nacatoch sand in Caddo Parish and from the deep oil sands of northwestern Louisiana. The sample from the Nacatoch sand (Dawes well) affords the most valuable comparison, because this is the approximate equivalent of the sands in the Powell pool. Northwestern Louisiana does not appear to contain any producing sands equivalent to the Corsicana, and the exact relations of the sand of the Angus pool are unknown. It may prove to be the equivalent of the Nacatoch sand, but if so, the quality of the oil is unlike that of the oil from any other pool in this sand.

Analyses of oil from the Corsicana and neighboring fields, Texas-Louisiana.

[Analyses by Bureau of Mines except as otherwise stated.]

Well and location.	Pool or district.	Depth of sand (feet).	Total depth (feet).	Crude (cubic centimeters and per cent).	Gravity.		To 150° C.		150°-300° C.		Residuum.		Unsaturated hydrocarbons.		Asphalt (per cent).
					Specific.	Baumé (°).	Cubic centimeters and per cent.	Specific gravity.	Cubic centimeters and per cent.	Specific gravity.	Cubic centimeters and per cent.	Specific gravity.	Crude (per cent).	150°-300° C. (per cent).	
Corsicana field, Tex.:															
Hartzell Oil Co., No. 8, south of Angus.	Angus........	560±	725-750	100	0.8279	39.1	20	0.7160	45	0.8005	35	0.8950	10	4	0
Marnet Oil Co., Robbins, Nos. 7 and 12, 2 miles southeast of Corsicana.	Corsicana.....	1,108 1,130	1,131 1,155½	100	.8304	38.6	21	.7238	48	.8150	31	.9130	12.8	4	0.83
Houston Oil Co., J. C. Blankenship, Nos. 1-7, 3 miles north of Corsicana.	.....do........	975±	1,000±	100	.8314	38.4	18	.7165	43	.8030	39	.8970	12	5	.66
J. S. Gibson, No. 16, 4 miles south of Corsicana.	Powell........	658	850	100	.8679	31.3	10.5	.7400	44.5	.8365	45	.9205	18.8	2	.53
Wright, No. 6, 5 miles southeast of Corsicana.	.....do........	....	860	100	.9109	23.7	1	....	33	.8680	66	.9260	30	13	1.14
J. O. Burke, No. 18, 1½ miles south of Powell.	.....do........	881	7,892	100	.9144	23.1	2	....	33	.8700	65	.9220	26	12	1.26
De Soto—Red River field, La.:															
Standard Oil Co., scales No. 1, sec. 35, T. 13 N., R. 12 W.	Naborton.....	2,410	....	100	.8069	43.5	19	.7230	50	.7960	31	.8870	8.8	6	0
Producers Oil Co., Christine, No. 16, near Naborton, De Soto Parish.	.....do[a]......	....	1,186	100	.7973	46.6	27	.7200	55.5	.7990	17.5	.9050	8.8	6	.09
Caddo field, La.-Tex.:															
Producers Oil Co., McCue Levee Board No. 2, sec. 36, T. 21 N., R. 16 W.	....	2,180	2,221	100	.8969	26.1	2.5	....	35	.8540	62.5	.9130	21.2	7	2.01
Dawes well, sec. 36, T. 22 N., R. 16 W.[b]	....	....	1,050	102.9	.9253	21.3	....	....	17.0	.8406	85.9	.9302	....	....	.22

[a] Oil from chalk rock.

[b] Harris, G. D., Oil and gas in Louisiana: U. S. Geol. Survey Bull. 429, p. 131, 1910. Analysis by U. S. Geological Survey: Oil from Nacatoch sand.

In interpreting the table, it should be remembered that the gravity of the oil distilled at temperatures up to 150° C. corresponds approximately to that of gasoline, though in practice the gasoline supplied by the refineries is intended to meet the requirements of the market, and as the result of distillation to a somewhat higher temperature it may be of slightly lower gravity than that obtained from the samples.

The oil obtained between the maximum temperature of gasoline distillation and 300° represents the kerosene. The residuum is used as a fuel and in the manufacture of the heavier petroleum products, such as lubricating oils.

The determinations set forth in the table were made from small samples obtained from only a few of the wells and may not be altogether representative of the character of the oils in the different pools. The sample from the Angus pool compares very favorably with those from the Corsicana pool. These lighter oils may be contrasted with the samples from the Gibson, Wright, and Burke wells, which show the quality of the oil from the Nacatoch (?) sands of the Powell district. The Gibson well supplied oil that is only slightly heavier than that of the Angus and Corsicana pools, the difference being most marked in the quantity of gasoline that can be obtained from it. This oil should be valuable for refining, especially when the lighter products, such as gasoline, are in demand. The samples from the Wright and Burke leases were much heavier than the others and yielded only about two-thirds as much kerosene. The quantity of residuum is naturally higher in the heavier oils than in the lighter oils.

The percentage of unsaturated hydrocarbons in the oils is variable. The unsaturated hydrocarbons in the gasoline are negligible, because they are not distilled in quantity below 150°, but in the kerosene the percentages are noticeable, though the sample from the Gibson well shows an unusually small amount. In thorough refining the unsaturated hydrocarbons will be largely removed and the amount of kerosene will thereby be diminished.

The sample from the Nacatoch sand in the Caddo field (Dawes well) is somewhat heavier than any of the samples examined from the Corsicana field. The oil is used as a fuel and is much less valuable for refining than the oils of the Powell field.

The sample from the Scales well, in De Soto Parish, La., is lighter than any of those from the Corsicana field, but the sample from the McCue Levee Board well, in the Caddo field, is of but very little better grade than the heavier oil of the Powell district, obtained from the Wright and Burke leases. The oil from the Christine well, of the De Soto field, more nearly represents the high-grade oils of northwestern Louisiana than either the Scales or McCue Levee

Board samples. It is the lightest oil represented in the table; its gasoline and kerosene contents are higher than those shown by any of the samples from the Corsicana pool, and the residuum is correspondingly lower. The oil from this well is from the chalk rock, but in composition it resembles the higher-grade oils from the deep sand of the Caddo field more than the oils from the chalk.

Asphalt was present in all the samples from the Corsicana field except one, but the percentage was small in most of the samples. The percentage of asphalt in the sample from the McCue Levee Board well is unusually high; the other samples from northwestern Louisiana contain practically no asphalt.

GAS.

The gases from the upper part of the Upper Cretaceous series are similar in composition in the different fields, as shown by the accompanying table. The combustible constituent that forms a very large proportion of all of them is methane (CH_4); the minor constituents are carbon dioxide (CO_2) and nitrogen (N_2). Some of the deeper gases in the lower part of the Upper Cretaceous and the sample from the Petrolia field contain more or less ethane (C_2H_6), but this constituent is not present, so far as has been learned by analyses of a number of samples, in any of the gases from the upper part of the Upper Cretaceous. The presence or absence of ethane has sometimes been used as a means of determining whether a sand contains oil in addition to gas, it being assumed that if no ethane is present there is no oil in the sand. This assumption is erroneous, because the sand that supplied the Edwards well, in the Caddo field (No. 4 in table), contains oil in the same part of the field where the gas sample was taken.

Analyses of gas from the Corsicana and other fields.

[By Bureau of Mines.]

	1	2	3	4	5	6	7
Carbon dioxide (CO_2)	1.7	Trace.	0.0	1.0	7.30	0.2	0.2
Oxygen (O_2)	1.1	0.0	.0	.0	.0	.0	.1
Methane (CH_4)	91.9	98.5	96.5	98.5	54.5	52.7	92.4
Nitrogen (N_2)	5.3	1.5	3.5	.5	38.2	37.8	3.9
Ethane (C_2H_6)	....	....	....	....	....	9.3	3.4
	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Specific gravity determined	0.60	0.56	0.57	0.58	0.79	0.78	0.60
Specific gravity calculated	....	....	.57	.57	....	....	.59
Heating value, in British thermal units, at 0° C.	979	1,052	1,027	1,030	580	755	....

1. Well No. 1 on Mackey lease, near Corsicana, Tex.
2. Well on Anglin lease of Robinson Oil & Gas Co., Mexia-Groesbeck field, Tex. U. S. Geol. Survey Bull. 629, p. 102, 1916.
3. Well on L. B. Phillips lease of Southwestern Gas & Electric Co., 10 miles west of Shreveport, La. Depth 1,000 feet.
4. Edwards well No. 1 of Southern Oil & Gas Co., sec. 23, T. 21 N., R. 11 W., Caddo field, near Vivian, La. Depth 1,040 feet.
5. Swamp gas.
6. Beatty well No. 1, Petrolia field, Tex. U. S. Geol. Survey Bull. 629, p. 41, 1916.
7. P. H. Youree well No. 3 of Gulf Refining Co. of Louisiana, sec. 33, T. 17 N., R. 14 W., south of Shreveport, La.

Because of difficulty in collecting sample No. 1, the only one obtained from the Corsicana field, some air was included, which resulted in a slight increase in the carbon dioxide, the introduction of oxygen, and a considerable increase in the amount of nitrogen. This brought about a lowering of the percentage of the combustible constituent methane and a consequent lowering in the heating value. In the samples of gases obtained from the Upper Cretaceous in the Mexia-Groesbeck field (No. 2), the Shreveport field (No. 3), and the Caddo field (No. 4), the percentages of the constituents other than methane are small, and their importance depends upon the fact that they are inert and require a certain amount of heat to increase their temperature, thereby lowering the heating value of the gas. The heating value is expressed in British thermal units.[1] It depends upon the pressure to which the gas is subjected, and a uniform pressure equivalent to that of a column of mercury 760 millimeters high has been used as a standard in making the determinations. The low heating value of the sample from the Corsicana field is probably due to the presence of air in the sample.

The composition of these gases may be contrasted with that of a swamp gas (No. 5) and that of the gas from the Petrolia field (No. 6), in which the low percentages of methane are accompanied by low heating values. Sample No. 7 represents the deep gas from the Shreveport field and shows the general character of the gases from the lower part of the Upper Cretaceous, though some of these gases contain no ethane and others contain more than this sample.

The gases obtained from the upper sands of the Upper Cretaceous compare favorably in heating value with those from the California fields, though some of the samples from Orange and Ventura counties, Cal., have heating values ranging from 1,100 to 1,240 British thermal units. The number of available analyses of Oklahoma gases does not warrant definite conclusions concerning their relative values, though apparently some of them are about the same as the best Upper Cretaceous gases of Texas and Louisiana and some are slightly higher in heating value. Most of the gases from Pennsylvania and West Virginia have higher heating values, many of them exceeding 1,200 British thermal units.

ORIGIN.

The oil of the Corsicana field is believed to have originated from organic matter in the shales that inclose the sands and to a minor extent in the sands themselves. The evidence in favor of local origin is given in the following discussion of migration and accumulation. The character of the organic matter that was the source of the oil and gas can not be easily ascertained, though apparently both vegetable and animal matter of marine origin are present. The entire series of beds between levels nearly 600 feet below the lowest sand and 700 feet above the highest sand is of marine origin but was formed near the shore, as is shown by the abundance of land-derived sediments. No remains of terrestrial plants or animals have been found in these sediments, and such remains were probably not abundant enough to yield much of the oil and gas if those substances were formed in place. Although oil may be transported mechanically with sediments, as noted by Stuart,[1] it is improbable that a large amount would be accumulated in that way, and origin from the organic matter in the sediments is believed to be more probable.

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[1] A British thermal unit is the amount of heat required to raise 1 pound of water 1° F. at or near its maximum density (about 39.1°).

The conclusion that the oil and gas were derived from marine plants or animals, or both, is strengthened by the presence in the sands and associated shales of remains of Foraminifera and carbonized residues of what are believed to have been marine plants.

MIGRATION.

VERTICAL MIGRATION.

The productive sands are included in a series of massive clays that would prevent extensive migration of the oil and gas in a vertical direction except where there were faults of large displacement. The region has been thoroughly prospected, and the geology has been studied in sufficient detail to indicate that no such faults exist in the field. Vertical migration between the different sands has not occurred, as is shown by the presence of gas in some of the sands below the beds that yield oil. The presence of the oil and gas in this field is in itself evidence of the absence of extensive vertical migration, because they would have escaped to the surface if uninterrupted vertical migration had been possible, whereas no seepages of oil or gas are known in this field.

The first sand beds encountered below the producing sands belong to the Woodbine sand, and that migration upward from this sand or from lower sands has not occurred is shown by the difference in composition of the water in the sands. The accompanying analyses of water from the Woodbine sand and the Corsicana sand show that the shallower sand contains strong brine, and that the water from the Woodbine is comparatively fresh.

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[1] Stuart, Murray, The sedimentary deposition of oil: Geol. Survey India Rec., vol. 40, pp. 320-333, 1910.

Analyses of water from the Corsicana and Woodbine sands.

[Parts per million.]

	1	2		1	2
SiO_2	260	44	K	422	
Fe	Trace.	Trace.	CO_3	0	48
Al	25		HCO_3	27	1,390
Ca	570	22	SO_4	0	Trace.
Mg	146	9.1	Cl	14,292	2,411
Na	8,045	2,128	NO_3		0

1. Robbins wells Nos. 6, 7, and 12, and Polk wells Nos 7, 8, and 10, Corsicana pool, near Corsicana, Tex. Water from Corsicana sand. S. C. Dinsmore, analyst.
2. Natatorium well, Corsicana, Tex. Water from Woodbine sand at depth of 2,360 feet. S. C. Dinsmore, analyst.

If there had been sufficient migration to bring the oil from the Woodbine sand, or through the Woodbine from lower sands, enough water would probably have risen from the Woodbine to dilute the brine in the higher sands.

HORIZONTAL MIGRATION.

The distribution of the sands in the Corsicana field favors migration only in a nearly horizontal direction, approximately parallel to the beds. The productive sands are fine grained, and the water does not escape freely in the direction of the dip. It is of course probable that somewhere along the dip the sand beds give place to shale, but this change to finer-grained material must occur some distance southeast of the oil field, because the Corsicana sand has been found in wells some distance beyond the productive area, and the Nacatoch (?) sand was probably encountered in the well of the Mitchell-Crittendon Co., 4 miles northwest of Malakof, where it contained a large amount of salt water and enough gas to burn at the mouth of the well. The sands in the Corsicana field, though fine grained, are apparently very porous—in fact, fine-grained sands are likely to be more porous than coarse-grained sands, because in most coarse sand there is enough fine material to partly fill some of the pores between the larger grains. The fine-grained sands in the Corsicana field have a large aggregate pore space but do not favor free migration of fluids, because of the smallness of the individual openings between the sand grains. The small amount of movement of fluids in the sands is indicated by the presence of salt water within 4 or 5 miles of the outcrop of the formation. This salt water does not indicate, however, that there has been no movement of the fluids away from the outcrop, as the original position of the outcrop, before erosion occurred, was some distance farther northwest than at present, and fresh water may have migrated downward from the outcrop at about the same rate as the change in its position resulting from erosion.

In the Corsicana field and along the strike of the Nacatoch (?) sand for a distance of 100 miles both north and south of the field salt water is found near the outcrop in the lateral extensions of the sand.

ACCUMULATION.

It is supposed by many geologists that the transfer of oil and gas from shales to sands is the result of pressure from the materials deposited upon the petroliferous beds. The aggregate weight of the overlying formations may of course be large, but it was added very slowly as the sediments were deposited particle by particle, and the process of compacting the shales and associated sands kept pace with the addition of the materials to the overlying formations. In this process the amount of pore space in both sands and shales was reduced—that of the sands by readjustment between the more or less angular grains. At the same time and subsequently a certain amount of cementation took place which further reduced the pore space and increased the rigidity of the beds, especially those of sandstone, which consisted of grains that in themselves were strong enough to be rigid. This compacting and cementing must have resulted in the transfer from the shales to the sands of a part of the salt water that had been included in the beds when they were deposited and, with the water, some of the oil and gas that had already been formed, because the shales were softer and the aggregate pore space was reduced more than the aggregate pore space of the sandstones.

After the compacting that resulted from the deposition of the overlying formations both shales and sandstones were subjected to folding, which caused further adjustment between their component particles. In the later stages and possibly throughout all the period of folding the shales were subjected to greater reduction in volume than the sands because they had originally greater pore space and were less rigid. This resulted in the transfer of fluids, consisting in part of salt water and in part of oil and gas, from the shales into the sands. The oil and gas thus transferred to fine-grained sandstone or sand were free to migrate laterally, as they were not in the dense shales.

According to the writers' interpretation of the conditions in the Corsicana field capillary forces, together with the force of gravity, produced some segregation of the oil and gas from the salt water during their migration up the dip. Although the folding was slow, there may have been a sufficient amount of fluid forced into the sand at times to cause a slight movement up the dip toward the outcrop, and such a movement would assist in the accumulation of the oil and gas in the higher structural positions. Circulating waters doubtless brought both oil and gas to the pools, and these were added to the stores accumulating under the influence of gravity and capillary attraction. The oil accumulated by circulating fluids would naturally be gathered where the circulation was arrested, as for example around the north end of the Mildred pool. Some accumulations occur on areas of steep dip beyond the lower margins of areas of lower dip, as in the Clements-Buchanan pool. If perfect hydrostatic adjustment had been attained, and if the sands were uniform, these areas of low dip would have been the most productive, because the gas and oil would have collected there, but the decreased dip checked the upward migration of the oil and gas, and this check, together with differences in the porosity of the sand, in some places prevented the accumulation of oil and gas on the high portions of the folds, in the areas of low dip. The lack of vigorous circulation and the variations in the porosity of the sands have hindered accumulation of the oil and gas in strict accordance with the structure.

PRODUCTION.

DAILY PRODUCTION.

No large wells comparable to those of the salt-dome fields of the coastal region of Texas and Louisiana or to those of the stratum fields of northwestern Louisiana have been drilled in the Corsicana field; in general the wells of this field are small producers but have a relatively long life. In the early history of the field the maximum initial daily production of the best wells did not exceed 200 barrels and in only a few wells has the initial production exceeded 100 barrels. The most productive individual wells were drilled in the Powell district, where the variation in initial production was large. The average production of the wells in the Powell and Corsicana districts, however, is probably not very different. The early wells in the Corsicana pool produced initially from 15 to 50 barrels a day; in the Burke pool, at Powell, from 10 to 200 barrels; and in the Angus pool 10 to 15 barrels.

Average initial daily production, in barrels, of oil wells drilled in the Corsicana field, 1908–1915.

[From U. S. Geol. Survey Mineral Resources.]

<table>
<tr><th>Year.</th><th>Corsicana district.</th><th>Powell district.</th></tr>
<tr><td>1908</td><td>5.1</td><td>12.3</td></tr>
<tr><td>1909</td><td>6.2</td><td>7.8</td></tr>
<tr><td>1910</td><td>3.2</td><td>5.3</td></tr>
<tr><td>1911</td><td colspan="2">5.4</td></tr>
<tr><td>1912</td><td colspan="2">6.4</td></tr>
<tr><td>1913</td><td colspan="2">4.0</td></tr>
<tr><td>1914</td><td colspan="2">2.8</td></tr>
<tr><td>1915</td><td colspan="2">2.0</td></tr>
</table>

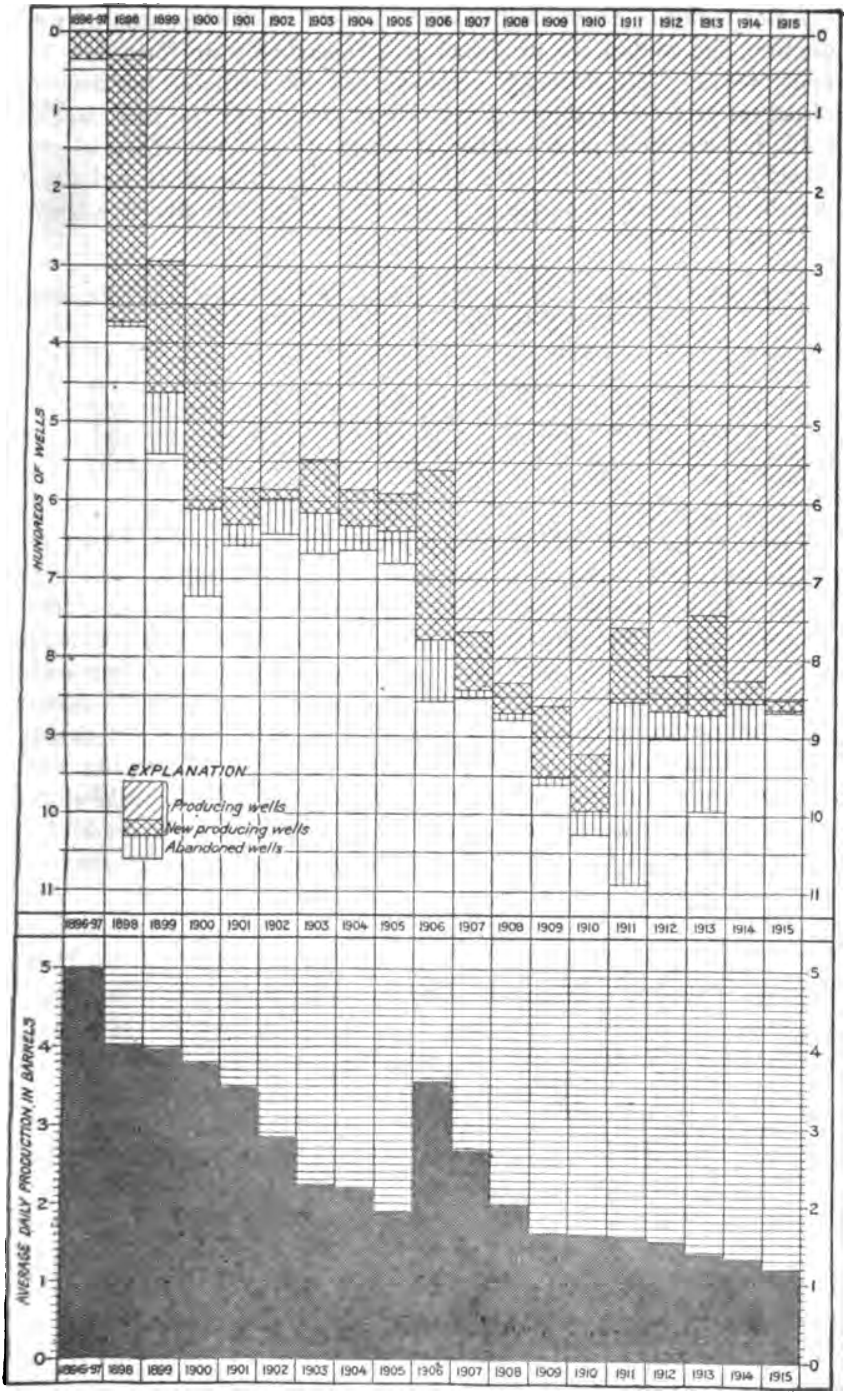

FIGURE 31.—Diagram showing average daily production of wells, number of producing wells, number of new wells, and number of abandoned wells in the Corsicana oil and gas field, Tex., 1896–1915.

After a rather rapid decline during the first few months of production, the wells have produced at a remarkably uniform rate for many years. Unfortunately, statistics are not available for the construction of a curve showing the rate of decline of the wells in this field; but the wells on a number of leases in the Corsicana pool produced almost as much in 1914 as in 1903, and some other wells that had been cleaned and drilled a few feet deeper produced more in 1914 than in 1902.

Average daily production per well, in barrels, on two leases in the Corsicana district during January, 1902–1904 and 1915.

Year.	1	2
1902	1.80	1.42
1903	1.22	1.15
1904	1.13	
1915 (well cleaned)	2.11	1.54

The average daily production per well in the Corsicana field for the years 1898 to 1915, as computed from the statistics given in Mineral Resources of the United States, is shown in figure 31. This diagram shows an abrupt drop in 1898, the second year for which the daily production was calculated, and then a gradual decline until 1905. In 1906 the Powell district was discovered and the average daily production of this district was included with that of Corsicana, resulting in an abrupt rise in the average daily production per well. The decline during the next two years was rapid, because the early wells in the Powell district came in with a fairly large yield but quickly declined. Since that time the decline has been very gradual.

LIFE OF WELLS.

Many wells in the Corsicana field have been producing for 15 to 18 years, although a greater number have been abandoned after having been pumped a shorter period. The following table gives statistics of the wells that have been drilled annually from 1896 to 1915:

Wells drilled in Corsicana oil field, Tex., 1896–1915.

[From U. S. Geol. Survey Mineral Resources.]

Year.	Total completed.	Producing Dec. 31.	Dry.	Gas.	Abandoned.	Year.	Total completed.	Producing Dec. 31.	Dry.	Gas.	Abandoned.
1896–97	43	37	6			1908	[g] 55	38	17	([f])	([f])
1898	374	342	[a] 28	4	7	1909	[h] 123	91	29	3	([f])
1899	268	169	[a] 90	9	79	1910	[i] 118	78	45	([f])	([f])
1900	373	[b] 261	[a] 98	14	112	1911 [j]	39	20	19	([f])	([f])
1901	68	[c] 47	16	5	27	1912 [j]	24	17	7	([f])	([f])
1902	28	[d] 12	13	3	45	1913 [j]	4	3	1	([f])	([f])
1903	100	70	23	7	51	1914 [j]	15	10	5	([f])	([f])
1904	74	46	26	8	31	1915	1	1			
1905	68	48	18	2	41						
1906	330	217	100	13	79	Total [k]	2,224	1,575	586		
1907	[e] 120	74	46	([f])	([f])						

[a] Includes 2 artesian wells.
[b] Includes 56 in Powell district.
[c] Includes 10 in Powell district.
[d] Includes 2 in Powell district.
[e] Includes 104 in Powell district.
[f] Data not available.
[g] Includes 42 in Powell district.
[h] Includes 118 in Powell district.
[i] Includes 91 in Powell district.
[j] Does not include wells in Powell district.
[k] Does not include wells in Powell district for 1911–1914.

Approximately one-third of the productive wells that had been drilled prior to the end of 1905 had been abandoned at that time, and as most of these wells had been drilled between 1898 and 1900, the average age of the wells was then about 6 years. At this rate all the wells would be abandoned in 18 years, and the average life of a well would be roughly 9 years. As many of the abandoned wells were located near the edge of the pool, where salt water would drown them in a short time, this figure for the average life of a well might seem to be too low, but a consideration of the total number of wells drilled to 1914, their average age, and the number of abandoned wells bears out the same conclusion—that the average life of a well in the Corsicana field is approximately 9 or 10 years. It must be remembered, however, that many of the wells are pumped when they yield only a small fraction of a barrel a day, because, with the multiple system of pumping, the pumping of an individual well may not have much effect on the cost of operating a lease.

YEARLY PRODUCTION.

The maximum annual production of 829,560 barrels in the Corsicana pool, the light-oil district, was reached in 1900, four years after the pool was discovered. The production has declined gradually since that time. The Powell district, which yields heavy oil, was discovered in 1900 and reached its maximum annual production of 673,221 barrels in 1906. The field as a whole also reached its maximum production in 1906, when it yielded more than 1,000,000 barrels of oil. It will probably be many years, however, before the field is entirely exhausted.

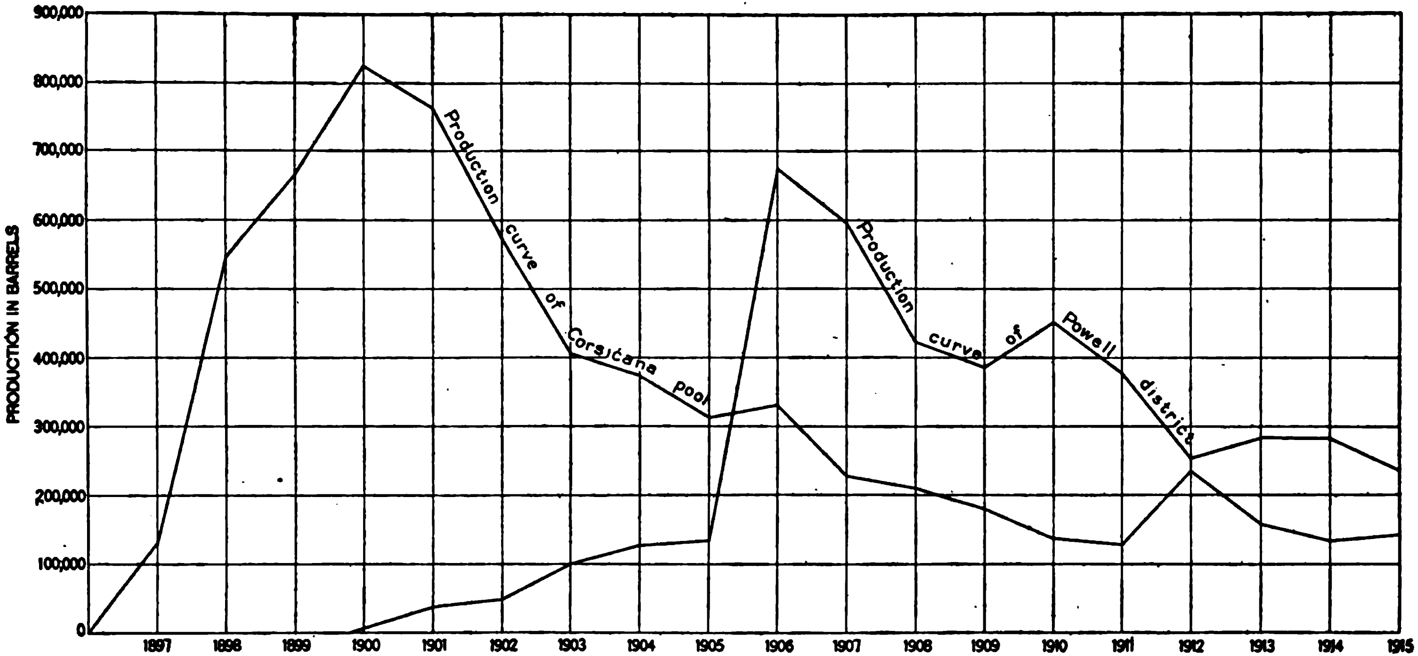

FIGURE 32.—Diagram showing production of oil in the Corsicana pool and Powell district, Tex., from discovery until 1915.

The production of the Corsicana field is shown in the following statistical table and also by figure 32:

Oil produced in the Corsicana field, Tex., in barrels, 1896–1915.

[From U. S. Geol. Survey Mineral Resources.]

Year.	Corsicana district.	Powell district.
1896	[a] 1,450	....
1897	[a] 65,975	....
1898	544,620	....
1899	668,483	....
1900	829,560	[a] 6,479
1901	763,424	[a] 37,121
1902	571,059	46,812
1903	401,817	100,143
1904	374,318	129,329
1905	311,554	132,866
1906	332,622	673,221
1907	226,311	596,897
1908	211,117	421,659
1909	180,764	383,137
1910	137,331	450,188
1911	128,526	373,055
1912	233,282	251,240
1913	158,830	282,476
1914	133,811	282,279
1915	143,275	237,410
	6,418,129	4,404,312

[a] Includes a small quantity produced elsewhere in Texas.

PRODUCTION PER ACRE.

The productive area of the light-oil district, as outlined on the map (Pl. XXI), including the Corsicana, Angus, and Tilton-Havener pools, is approximately 3,580 acres. The production from this area to the end of 1915 was 6,418,129 barrels, and thus the average production per acre has been 1,792 barrels. From the production curve shown in figure 32 the total reserve of the pool at the end of 1915 is estimated at 558,000 barrels, or 156 barrels per acre, making the estimated ultimate production 1,948 barrels per acre.

Another figure for the area of the Corsicana pool was obtained by dividing the productive area into 10-acre tracts and counting all the tracts on which there was one or more productive wells and eliminating those on which there were none. The area thus arrived at was 3,185 acres. On this acreage the production per acre to the end of 1915 was 2,015 barrels, the reserve at that time was 175 barrels, and the ultimate production would be 2,190 barrels. The yield of 2,015 barrels per acre is equivalent to a layer of oil covering an acre 0.26 foot deep and 2,190 barrels per acre to a layer 0.28 foot deep. It is impossible, of course, to determine the exact area from which the oil has been obtained, just as it is impossible to estimate the percentage of oil that is recoverable. However, owing to the low gas pressure and the lack of vigorous hydraulic circulation in this pool, it is believed that the productive area is probably nearer 3,185 than 3,580 acres.

In like manner the productive area of the Powell district (including all the small pools of heavy oil) is 2,700 acres, as outlined on Plate XXI, or 2,465 acres, as determined by counting 10-acre tracts containing one or more wells. The production to the end of 1915 was 4,404,312 barrels—1,631 barrels per acre for 2,700 acres, or 1,787 barrels per acre for 2,465 acres. The reserve at that time, as estimated from the production curve shown in figure 32, was 1,135,000 barrels—420 barrels per acre for 2,700 acres, or 456 barrels per acre for 2,465 acres. The total ultimate production is estimated to be 2,051 barrels per acre for 2,700 acres, or 2,243 barrels per acre for 2,465 acres.

VALUE.

The table below shows the average value per barrel of the oil in the Corsicana and Powell districts and a number of other fields of the United States.

Average price of oil per barrel in different fields of the United States for 1913, 1914, and 1915.

[From U. S. Geol. Survey Mineral Resources.]

Field or pool.	1913	1914	1915	Field or pool.	1913	1914	1915
Texas:				Oklahoma	$0.937	$0.778	$0.579
Corsicana	$0.987	$0.923	$0.744				
Powell	.766	.600	.449	California: San Joaquin Valley	.444	.448	.326
Wichita County	1.001	.825	.628	Colorado: Florence	.900	.886	.859
Humble	.965	.548	.482	Wyoming	.493	.472	.522
Louisiana:				Indiana	1.337	1.159	.929
Jennings	.974	.909	.486	West Virginia	2.492	1.908	1.561
Caddo	1.003	.948	.710	Pennsylvania	2.487	1.906	1.586

CONDITIONS AFFECTING EXPLOITATION.

METHODS AND COST OF DRILLING.

Both hydraulic rotary and cable tools have been employed in the Corsicana field. Because of the softness of the strata and the absence of thick beds of hard rock, the rotary method is the quickest and most economical; it is stated that as much as 1,000 feet has been drilled in 36 hours by this method. It has the disadvantage of obscuring the presence of traces of oil and beds of fine sand and of putting the productive sand under a heavy pressure of mud-laden water. This method has been satisfactory, however, especially in proved territory where the underground conditions are well known from the records of previous wells.

Wells in this field are drilled at a cost of 50 to 60 cents a foot, and the total cost of a well, exclusive of casing, is about $550 to $650 in the Corsicana district and $350 to $450 in the Powell district. If a paying well is not obtained, the casing is pulled out, and all that is lost is the cost of drilling. With a rotary rig it requires from two days to a week to complete a well in the Powell district and from three to ten days in the Corsicana district.

WATER CONDITIONS.

The water conditions in the different pools, as described under the heading "Occurrence of oil and gas," are simple and offer few complications. In the Corsicana pool there is in general one productive sand, and that contains water in troublesome quantities only around the border of the pool, although a small amount of water is pumped with the oil over a large part of the pool.

In the Corsicana pool the surface casing, which is usually 6 or 6¼ inches in diameter, is set at 40 to 190 feet below the surface; the deep casing, which is usually 4 or 4½ inches in diameter, is set on the top of the oil or gas sand, and the oil is pumped through a 2-inch tube which extends to the bottom of the well. The wells are drilled to different depths in the productive sand, from a few feet to 50 feet or more, but generally about 30 feet, the depth depending on local conditions.

In the Powell district water is usually troublesome only in the lower productive sand, and there only near the edges of the individual pools. In the center or near the western limit of each pool there is usually little water, except in the Burke pool, and many of the wells are drilled below the base of the lowest sand. The surface casing, usually 6¼-inch, is set at 50 to 100 feet; the deep casing, usually 4-inch, is set at the top of the highest productive sand; and the interval between the lower end of the 4-inch casing and the bottom of the well is commonly cased with a 3½-inch perforated liner. The oil is pumped through a 2-inch tube.

METHOD OF PUMPING.

All the wells in the Corsicana field are pumped by the multiple system, which consists of a centrally located power station, pumping frame, transmission lines or jerker lines running to the individual wells, and a pumping jack at each well. The power for operating each pumping station is furnished by a natural-gas engine supplied with casing-head gas from the wells that are being pumped or by a steam engine burning crude oil. The pumping frame consists of a horizontal shaft that drives a vertical shaft to which is attached one or more eccentrics. The jerker lines are attached to the outer edge of the eccentrics and are pulled a distance corresponding to the throw of the eccentric at each revolution, usually about 2 feet. The horizontal pull of the jerker line is converted into a vertical pull at the well by pumping jacks to which are attached the sucker rods.

By this method 15 to 25 wells, suitably located, may be economically pumped from one station. Usually one man operates two stations, most of which are run only a few hours each day. The oil is pumped into small tanks, which are connected by pipe lines with loading racks or large storage tanks.

CLEANING THE WELLS.

The oil in the Powell district is thick and ropy and contains a considerable amount of an oil, water, and clay emulsion, which gradually chokes up the wells and makes it necessary to clean them. Furthermore, a considerable amount of fine sand, carried up with the oil, cuts the leather cups used in pumping. Generally the cups require changing about once a month, although in some parts of the field they last much longer. Where the derricks have been taken down after drilling, as is the usual practice, the sucker rod is pulled out and the wells cleaned with the aid of a metal or wooden gin pole.

FUTURE DEVELOPMENT.

Extensive drilling has been done in and around the Corsicana field during the last 20 years, and as records of the location and depth of many of these wells are not available, it is difficult to recommend new territory for testing.

It is believed that no adequate tests have been made of the Corsicana sand in the Powell district, where the structure is most favorable for the accumulation of oil and gas, as in the Burke pool. The presence of a show of oil and gas in what is believed to be the Corsicana sand in the G. W. Speed well, where the structure is considered unfavorable, makes it seem somewhat likely that this sand may contain oil or gas. It is considered worthy of a test in the south-central part of the J. O. Burke 224-acre tract south of Powell. So far as available records show, the Corsicana sand has not been reached in either the Edens or the Chatfield gas pool, and it is possible that a sand equivalent to it, or a deeper one, may underlie these pools and may be found to be productive. Deeper drilling in the parts of both these pools where the structure is most favorable is justified.

The presence of water that is only slightly saline in the Woodbine sand at Corsicana suggests but does not prove the absence of oil or gas in that formation in this field. As the Woodbine is an important oil and gas bearing formation in northwestern Louisiana, it is considered worthy of a test in the area of favorable structure in the Burke pool, in spite of the poor showing made in the refinery well and deep-water wells in Corsicana.

In general, wildcat testing is most likely to be attended with success along the trend of the formations to the north and south, as shown on the sketch map (Pl. XVIII). The Mexia-Groesbeck, Thrall, and San Antonio fields follow the general trend of the formations to the south of the Corsicana field. The absence of good exposures of the formations along this belt makes it difficult if not impossible to locate favorable areas for drilling over much of this region.

THE PALESTINE SALT DOME, ANDERSON COUNTY, TEXAS.

By Oliver B. Hopkins.

INTRODUCTION.

The Palestine salt dome has been known for many years, having been described briefly by Penrose[1] in 1890 and by Dumble[2] in 1891. The dome was recognized through the occurrence of salt, which was obtained here in small quantities prior to 1890. The production of salt lapsed for many years, but recently the industry has been revived and a modern plant producing a large quantity of salt of various grades has been established. There are no conspicuous indications of oil or gas here, and so far no deep test wells for oil have been put down. The discovery of tarry oil in a deep well on the Keechi dome, 6 miles north of the Palestine dome, has stimulated interest in the oil possibilities of the domes of this area and has led to the leasing of the lands on and around them.

The writer spent one week in October, 1916, in studying the geology of this dome and the surrounding area. He wishes to offer grateful acknowledgment to Judge O. C. Funderburk, of Palestine, for assistance in the field, and to Mr. A. L. Bowers, president of the Palestine Salt & Coal Co., for information relating to the drilling of salt wells. L. W. Stephenson, of the Geological Survey, studied the Cretaceous fossils from the area, and to him the writer is indebted for much of the information concerning the age of the formations present.

LOCATION.

The Palestine salt dome is in Anderson County, eastern Texas, 6 miles south of west of Palestine. It lies immediately north of Town Creek about 6 miles from its confluence with Trinity River. This dome is roughly in line with the Keechi, Brooks, and Steen domes, to the northeast, and the Butler dome, to the southwest. (See index map, Pl. XXII.) It is about 6 miles from the Keechi dome and the same distance from the Butler dome. None of the domes along this line are at present productive of oil; the productive domes, such as the Humble, Dayton, and Saratoga, are limited to a relatively narrow belt along the coast. The nearest productive oil and gas fields are the Corsicana, which is 48 miles northwest, and the Mexia-Groesbeck, which is about the same distance west of this dome.

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[1] Penrose, R. A. F., jr., A preliminary report on the geology of the Gulf Tertiaries of Texas [etc.]: Texas Geol. Survey First Ann. Rept., pp. 33–34, 1890.

[2] Dumble, E. T., Anderson County: Texas Geol. Survey Second Ann. Rept., pp. 304–305, 315–317, 1891.

TOPOGRAPHY.

The Palestine dome is near the northwestern margin of a cuesta which was described by Deussen[1] as the "Nacogdoches wold" and which consists of a dissected, gently sloping dip plain, terminated landward by a line of hills with steep slopes. The superior elevation of this plain is due to the hardness of the surface rock, which is in part iron ore. The western part of this plain, in which the Palestine dome is situated, is much dissected and is rolling to hilly. It ranges in altitude above sea level from about 230 feet along Trinity River to 650 feet on the tops of the highest hills. The altitude in the immediate vicinity of the dome ranges from 280 to 350 feet.

The dominant topographic features of the area of the dome consist of a centrally located lake, Dugeys Lake, a sunken area, surrounded by a ring of hills, which in turn are bordered on the north, west, south, and southeast by the valleys of Wolfe and Town creeks. The hills forming the rim of the depression have an altitude of 330 to 350 feet above sea level, or 60 to 70 feet above the centrally located lake. The hills rise steeply on the west side and gently on the east and northeast sides of the lake, which occupies a natural basin but which is formed by the damming of its outlet. Of this basin Dumble[2] wrote in 1891:

> During the winter months it contains some water, but in summer it is dry, and there are small patches scattered here and there on which an incrustation of salt appears. The soil of the saline has the same appearance as that of the "black waxy" or *Ponderosa* clays soil. The timber appears to be encroaching on it gradually. The drainage from the surrounding hills builds delta-like formations farther and farther outward, and the trees push out on the edges of these.

The 280-foot contour on the accompanying sketch map indicates the areas normally covered by water, which has a maximum depth of about 4 feet. The lake is half a mile long and three-eighths of a mile broad and has an irregular shape. The salinity of the water in the lake is increasing, owing to the inflow of salt water from salt wells and the salt works. The broad flat that borders the lake on the south and east is barren of vegetation, owing to the precipitation of salt, which forms a white incrustation on the surface in dry seasons.

The unusual features of the topography are the central depression, the circular ring of hills, the courses of Town and Wolfe creeks,

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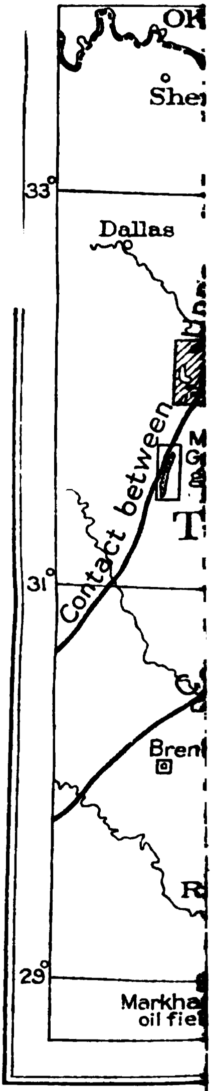
[1] Deussen, Alexander, Geology and underground waters of the southeastern part of the Texas Coastal Plain: U. S. Geol. Survey Water-Supply Paper 335, pp. 15–18, 1914.

[2] Dumble, E. T., Anderson County: Texas Geol. Survey Second Ann. Rept., p. 305, 1891.

U. S. GEOLOGICAL



INDEX MAP SH

which border the area on three sides, and the details of the drainage in the rim of hills. South of Dugeys Lake there is a gap in the hills, 30 or 40 feet below the hilltops, which has the appearance of a "wind gap" or a former stream channel. For a distance of one-third of a mile this channel is almost flat, and at some places water stands in it; within a quarter of a mile of the lake it dips steeply into the lake basin. It is evident that this is not a normally developed stream bed, as the gradient instead of being greatest near its head is greatest near its mouth, a feature which is due to the sinking of the lake area in relatively recent time. This channel is pushed back abnormally far toward Town Creek, and its valley is too large in proportion to the amount of water it carries. It is likely either that one branch of Town Creek originally flowed through this gap and into that creek by way of Dugeys Lake or that this channel has been partly formed through the process that gave rise to the lake. Before the sinking of the area of Dugeys Lake by reason of the solution and removal of the underlying salt, a small stream with its head near the center of the lake may have flowed southeastward into Town Creek, but the subsidence of the lake area diverted most of the water to the west and caused the lowering of the upper part of the watercourse sufficiently to make the water flow in the opposite direction. If this is the correct interpretation the diversion of the stream must have taken place when the bed of Town Creek was only slightly below the level of this abandoned channel.

A similar anomalous stream channel is found near the southeast end of the lake. Here the conditions are more nearly normal, but the broad, flat "wind gap" is conspicuous and points to recent stream adjustments.

The valley of Wolfe Creek is more mature than that of Town Creek, and as the creeks are of about equal size, it is suggested that Wolfe Creek has maintained its present course longer than Town Creek.

The Palestine road crosses a small branch of Wolfe Creek 1¼ miles north of east of the salt works at Little Saline, an open valley over which are scattered a few salt licks, or areas where the soil is salty and barren of vegetation. No drilling has been done there, but it seems likely that salt water finds its way to the surface along faults from the central salt core. It is possible, however, that rock salt may underlie this area at a relatively shallow depth.

Half a mile down Wolfe Creek from this locality there are a number of small circular areas where the ground is unstable and where the surface heaves up and down when walked upon. These areas are generally covered with a thick sod, which is underlain by soft blue mud, into which a stick can be pushed with ease 4 to 6 feet or more. These so-called quagmires, which are common on salt domes, are probably near faults or other openings along which water finds its way to the surface. The water about these quagmires is not briny and there is no evidence of gas or oil in their vicinity.

Other interesting features of the dome are the glades which surround it on all sides. These are low areas along stream valleys where no bushes or trees grow, and the principal vegetation is a peculiar swamp grass. The absence of a normal growth of vegetation on these areas suggests that the soil may be slightly saline, owing to the escape of salt-bearing water.

GEOLOGY.

STRATIGRAPHY.

SURFACE GEOLOGY.

GENERAL FEATURES.

Under normal structural conditions this area would lie near the contact of the Eocene Wilcox and Mount Selman formations and would be underlain by the Wilcox formation. Extensive local uplift, however, has brought to the surface and exposed over small areas Cretaceous formations that would normally be buried by several thousand feet of strata. The exposure of Cretaceous rock here thus represents an inlier which is 42 miles from its nearest outcrop. The normal succession of rocks for this area is shown in the accompanying table. Of the formations listed the Eagle Ford, Austin, Navarro, Wilcox, and Mount Selman and probably the Woodbine sand are exposed at the surface. If the Taylor and Midway formations are exposed, they have not been recognized. The area covered by the formations normally lying below the Wilcox is small, and only parts of the formations are exposed.

The Cretaceous rocks, although probably near the surface on all sides of the dome, are exposed best on its northwest and west sides; small exposures are found on its southeast side. Of these formations the Navarro covers much the larger area. The normal succession of the Cretaceous formations is obscured by faults that cause a duplication of outcrops. The succession of rocks is best shown on a small ridge a few hundred yards northeast of the salt works; here sandstones of Woodbine (?) age crop out on the crest of the ridge and are paralleled on its west side by narrow outcrops of the Eagle Ford, Austin, possibly Taylor, and Navarro, beyond which is the Wilcox, which completely encircles the dome.

Partial section of geologic formations involved in the Palestine salt dome.

System.	Series.	Formation.	Thickness.	Lithology.
			Feet.	
Tertiary.	Eocene.	Mount Selman formation.	350-600	Sands, in part highly glauconitic and fossiliferous, clays, lignite, and thin beds of iron ore.
		Wilcox formation.	450-650	Sand lenses, sandstones, clays, sandy clays, and lignites.
		Midway formation.	250	Clays and limestones of marine origin.
Cretaceous.	Gulf (Upper Cretaceous).	Navarro formatio.	600-900	Marls, bluish black, and glauconitic clays: blue clays with siderite and limonite concretions; yellow and brown sands with hard sandy concretions.
		Taylor marl.	800-1,000	Clay marls, blue, calcareous.
		Austin chalk.	400-500	Chalk, interstratified with thin beds of soft marl.
		Eagle Ford shale.	350-400	Shale and thin arenaceous beds of laminated limestone.
		Woodbine sand.	350-500	Sand, arenaceous clay, and clay.

WOODBINE SAND.

A narrow belt of gray to yellow friable sandstone and hard ferruginous sandstone containing scattered shells of probable Woodbine age crops out on a narrow ridge that projects into the lake a few hundred yards east of the salt works. This sandstone, which strikes N. 30° E. and dips 46° NW., parallels a narrow belt of limestone of Eagle Ford age on the west and a more conspicuous belt of Austin chalk still farther west but on the same ridge.

Samples of this sandstone with poorly preserved fossils were submitted for examination to L. W. Stephenson, who expressed the opinion that they are certainly of Cretaceous age and probably belong to the Woodbine sand. A definite determination was not possible, because the fossils could not be identified.

EAGLE FORD SHALE.

The only recognized exposures of the Eagle Ford shale occur on the ridge a few hundred yards east of the salt works, between narrow belts of Woodbine (?) sand and Austin chalk. They consist of a hard, somewhat flaggy fossiliferous limestone that appears to underlie the Austin chalk. Mr. Stephenson has identified *Ostrea lugubris* Conrad, *Plicatula* (?), and *Corbula* sp. in this limestone and considers it of Eagle Ford age. Only a few isolated exposures of this limestone are present, and these occur along the east side of the belt of Austin chalk, which dips steeply to the northwest.

AUSTIN CHALK.

The Austin chalk is exposed in the railroad cut just south of the salt works, on the hill one-third of a mile east of north of it, on the Palestine road, on the ridge immediately east of the road, and on the east slope of this ridge one-third of a mile northeast of the salt works. There are three parallel belts of chalk here, the duplication being caused by northeasterly faults. The chalk is massive, white to cream-colored and in part bluish gray, and argillaceous. It strikes in general northeast and dips 40°–50° NW. Mr. Stephenson has identified this chalk as Austin and has recognized in it two or more species of *Inoceramus*.

Fragments of chalk are present on the surface on the southeast side of the lake, but no ledges of it were found in place. The best exposures are in the railroad cut at the salt works, where about 25 feet of pure white to cream-colored and bluish-gray argillaceous chalk is exposed. It strikes N. 15° E., dips 48° NW., and is overlain by either Taylor or Navarro clay.

TAYLOR MARL.

The Taylor marl has not been recognized in outcrops in this area, although it is quite possible that part of the dark plastic clay here belongs to this formation. No fossils of Taylor age have been found.

NAVARRO FORMATION.

The Navarro formation is exposed over a semicircular area with a radius of about one-third of a mile extending from the salt works north and northeast almost to Wolfe Creek and in a smaller area three-fourths of a mile southeast of the salt works and about one-third of a mile southeast of the east end of Dugeys Lake. Fossils collected from a small draw at the Dugeys Lake locality were identified by Mr. Stephenson as *Ostrea plumosa* Morton, *Exogyra cancellata* Stephenson, and *Pecten quinquecostatus* Sowerby. He states that these fossils represent the *Exogyra cancellata* subzone of the *Exogyra costata* zone, or, in other words, the lower part of the Navarro formation of Texas.

The Navarro consists of soft bluish-gray clay shale and thin ledges of hard limestone. The shale weathers to dark-gray or black plastic clay, which is conspicuous along the road from the salt works to Palestine.

MIDWAY FORMATION.

The Midway formation has not been recognized in this area and is believed to be absent here as well as in the Keechi dome, 6 miles east of north. The absence of this formation at the surface may be due to faulting or to local unconformity between the Navarro and Wilcox. The absence of beds of Midway age at both the Palestine and Keechi domes, the great differences in the faunas of the Cretaceous and overlying Tertiary, and the great extent of the unconformity separating them, which doubtless records not only erosion but great diastrophic movement, make it seem highly probable that these domes began to be uplifted at the end of the Cretaceous period and that they were islands in the Midway sea on which no sediments were deposited.

WILCOX FORMATION.

The Wilcox formation entirely surrounds the Palestine dome and dips steeply in all directions away from its center. Near the inner margin of its outcrop the dips are steepest, ranging from 38° to 57°; they diminish away from the center of the dome, at a distance of a mile ranging from 20° to 30°, and within 2 or 2½ miles become almost horizontal. To the northeast and southeast the Wilcox formation disappears beneath the Mount Selman formation.

The Wilcox formation consists of lenticular beds of lignitic sand and clay and thin beds of sandstone and lignite; these materials are very irregularly bedded, and the individual beds vary widely from place to place. On Waterworks Branch of Town Creek, 1½ miles south of east of the salt works, the following section is exposed:

Partial section of Wilcox formation on Waterworks Branch.

[Strike N. 60° E., dip 24° SE.]

	Feet.
Sand, white to brown, hard, with leaf impressions	10
Lignite, in fairly uniform bed	5½
Sand, light gray to brown, carbonaceous, with leaf impressions	6
Clay, brown, carbonaceous, to bed of branch	2
	23½

Partial section of Wilcox formation in bluff of Trinity River at mouth of Town Creek, 12 miles southwest of Palestine.

Top of bluff.	Ft.	In.
Sand and gravel cemented by limonite	2–3	
Sand and sandy clay, gray, with thin beds of limonite	2	0
Sand, hard, green to brown	2	6
Iron ore, laminated		2
Clay, carbonaceous		6
Greensand		4
Clay, brown		2
Sandstone, soft, brown		10–12
Clay and sand, brown, laminated, carbonaceous, containing scattered concretions, more regularly bedded below than above		11
Iron ore, concretionary; iron carbonate on inside weathered to limonite on outside		1–4
Sand, brown, carbonaceous, highly cross-bedded, with vertical layers of ferruginous sandstone filling joints	8	0
Iron ore, concretionary, giving place along bedding to earthy lignite		6
Sand, carbonaceous, very irregularly bedded, containing irregular masses of brown clay	8	4
Clay, carbonaceous, sandy		10
Sandstone, soft, yellow		5
Clay, carbonaceous, sandy		10
Sand, yellow, with irregular concretionary layer at top	1	0
Clay, carbonaceous, hackly	1	0
Water level in Trinity River.		
	30	7

Numerous casts of elongated pelecypods are present in the sands and sandy clays near the top of this section.

The highly irregular character of the Wilcox beds in this area and the rather abrupt change in dip on the flanks of the dome led Deussen to believe that there was a slight upward movement of the dome in late Wilcox time, causing a local structural unconformity within that formation. This inference seems probable, but no definite proof of such an unconformity was found.

MOUNT SELMAN FORMATION.

The Mount Selman formation, the oldest formation of the Claiborne group in this area, skirts the north, east, and southeast sides of the dome at so great a distance from the center (3 to 5 miles) that it is only slightly disturbed by the uplift. The normal southwesterly trend of the formation is, however, deflected somewhat to the east. The dip of this formation is low and is measurable at few if any places near the dome.

The Mount Selman consists of massive sands, highly glauconitic sands, clays, and marls, with abundant shells. It is dominantly ferruginous and sandy. On weathering most of the beds turn red at first and become gray only after thorough leaching of the iron content. Beds of limonite are found at some places.

U. S. GEOLOGICAL SURVEY

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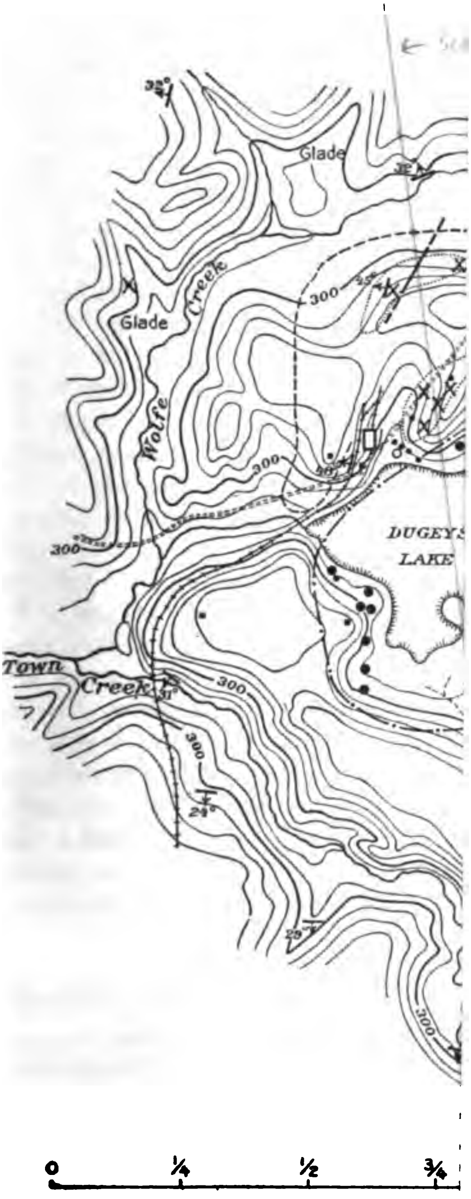

SKETCH MAP

UNDERGROUND GEOLOGY.

The deepest wells on the dome do not exceed 500 feet in depth, and few go down more than 250 or 300 feet. The drilling has been done entirely in search of salt, and where that has not been found within a few hundred feet of the surface the locations were abandoned in favor of others. Most of the wells reach rock salt at a depth of about 140 feet, or about 160 to 170 feet above sea level, the small differences in the depth being due to the surface topography; the upper surface of the salt is thus fairly level in the area near the lake. In the second farthest well to the northeast from the lake, however, the top of the salt was found at 77 feet above sea level, thus showing that the salt mass has a pronounced dip to the north from the nearest well to the southwest. A well drilled near the western margin of the lake on the west side of the railroad penetrated a jumbled mass of rock and shale to a depth of 500 feet without reaching salt; another well near the northwest margin of the lake penetrated 360 feet of rock without reaching salt. It thus seems that the salt mass dips strongly to the west and reaches a considerable depth near the western margin of the lake. No wells have been drilled on the east or southeast side of the lake, but it is inferred from the topography that this area is underlain by salt at no great depth. The area supposed to be underlain by salt at a depth of a few hundred feet is indicated on the accompanying map (Pl. XXIII).

The shallow salt wells penetrate about 85 feet of gray to yellow water sand and 40 feet of dark-gray to black sandy clay, below which is in places a cap rock of hard limestone of varying thickness. The casing is set on this rock and the well deepened through sand until rock salt is reached at about 140 feet. The main factor controlling the location of salt wells is the presence of a good cap rock which serves as a seat for the casing and also holds up the overlying strata until a large cavity is dissolved out underneath it. When the supporting salt is sufficiently removed this rock, being undermined, caves in, with the overlying formations, forming a large sink hole.

STRUCTURE.

Penrose[1] recognized the presence of an uplift here in 1889, saying:

> In many places on the top and slopes [of the hills] are seen outcrops of white chalky fossiliferous limestone with dark specks (glauconite). The fossils have been identified by R. T. Hill as belonging to the "glauconitic" beds of the Upper Cretaceous epoch and possibly represent the Ripley group of Alabama. This locality is over 50 miles east of the main Cretaceous area of central Texas and doubtless represents the remains of an island in the old Tertiary sea.

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[1] Penrose, R. A. F., jr., A preliminary report on the geology of the Gulf Tertiaries of Texas [etc.]: Texas Geol. Survey First Ann. Rept., pp. 83–34, 1890.

The existence of a dome here is proved by the presence of a Cretaceous inlier in an area of Tertiary rocks where the Cretaceous would normally be several thousand feet below the surface, by the presence of rock salt near the surface, and by the characteristic topography of a salt dome.

The occurrence of Cretaceous rocks at the surface, at a distance of 42 miles from their nearest normal outcrop, proves the presence of an uplift of great intensity. The best available information regarding the thickness of the formations involved in this uplift is given in Plate XXIII. As this dome is near the line of contact of the Wilcox and Mount Selman formations, the amount of uplift is equivalent to the thickness of the strata between the top of the Wilcox and the lowest formation exposed. The thickness of the strata between the top of the Wilcox and the top of the Eagle Ford, which has been definitely recognized, is 2,500 to 3,300 feet. If the Woodbine sand is present at the surface, as it probably is, the uplift is 350 to 400 feet greater. A moderate estimate of the maximum vertical movement of the Cretaceous formations is about 3,000 feet.

This local uplift is highly complicated by faults, many of which are indicated at the surface, although their exact location and extent have not been determined. How much of the vertical displacement found here is due to folding and how much to faulting is not known, but it is highly probable that faulting played as important a part as folding. The dip of the Cretaceous rocks is observable only on the north and west sides of the dome, where it is to the northwest, away from the center of the uplift.

The depressed area of the dome, which is considered to represent with fair accuracy the center of the uplift, is completely encircled by the Wilcox formation, which dips away from it in all directions, thus showing the quaquaversal nature of the dome. The Wilcox dips at angles of 30° to 57° at its outcrops nearest the dome, but the decrease in the rate of dip away from the center of the uplift is pronounced. The dip of the Cretaceous formations below the Wilcox outcrops is probably greater than that observed in the Wilcox, a feature which is characteristic of salt domes.

Viewed as a whole the Palestine dome is a quaquaversal fold on whose flanks are highly inclined beds that dip in all directions away from its center but become approximately horizontal within a few miles; the center of the uplift is extensively faulted, mainly in a northeasterly direction, producing an irregular distribution of the Cretaceous beds and a triplication of the outcrop of the Austin chalk. The structure in the Cretaceous formations is doubtless more complicated than in the Wilcox, as the dome, with the attendant folding and faulting, probably began to develop prior to the deposition of the Wilcox.

DEVELOPMENT OF THE DOME.

AGE OF FORMATION.

The great diastrophic movements that are known to have taken place in this region at the end of the deposition of the highest Cretaceous formation, the Navarro, and the absence of the earliest Tertiary formation, the Midway, in both the Palestine and Keechi domes suggest that the initial uplift of these domes occurred during the hiatus between the Navarro and the Midway and that the dome was an island in the Midway sea, around which sediments accumulated. It is likely that this island was degraded during this period, for in Wilcox time this area was at about the level of the surrounding country, and the deposits of that age probably extended over it. There may have been a slight upward movement during late Wilcox time, as Deussen[1] has suggested, causing the early Wilcox beds to be tilted at a greater angle than the later ones. However, the forces that produced the domes, if they became operative prior to the Wilcox deposition, must have been comparatively dormant during most of that time, and any previous upward movement must have been offset by erosion during Midway time. A considerable part of the uplift was in post-Wilcox time, as beds of Wilcox age are highly tilted around the flanks of the dome.

The Claiborne formations (Mount Selman, Cook Mountain, and Yegua) do not crop out near enough to the dome to record how much of the uplift occurred after their disposition; and no chronologic record of movement is left, although it doubtless took place, until recent time, when it was recorded by the physiographic development. If the Palestine and Keechi domes were developed at the same time as the Brenham dome, which has involved younger beds, their history may be expanded by inference from the history of that dome. The uplift in the Brenham dome since Cook Mountain time has been from 600 to 900 feet (see p. 276), and therefore it seems likely that the Palestine and Keechi domes also have been considerably uplifted since that time. This is likewise suggested by the deformation of the Claiborne beds in the area near the domes. The uplift in the Brenham dome was practically completed in Lagarto (Pliocene) time, as beds of that age are only slightly disturbed. It seems likely that the main uplift in these domes was completed during late Eocene, Oligocene, or Miocene time, and that only slight movements have taken place since then.

That there has been relatively recent movement, although of small amount, is proved by the stream adjustments that have taken place in the area. The dome was either degraded as fast as it was uplifted or it was base-leveled afterward, for in relatively recent time the dome appears to have had no topographic expression and the streams flowed in their normal courses over it; later a slight uplift occurred and the streams began to sink their channels and to shift their courses in adjustment to this movement. The abandoned "wind gaps" (see p. 255) were cut during this time. The uplift caused active solution and removal of salt from the top of the salt core, with the formation of large cavities, which finally caused the collapse of the crest of the dome and the gradual formation of the basin. Minor stream adjustments attended this change in the crest of the dome, with the consequent formation of the present topographic features shown on Plate XXIII and described on pages 254–256.

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[1] Deussen, Alexander, informal communication.

CAUSE OF UPLIFT.

Such an intensive and highly localized vertical uplift of quaquaversal form could be produced only by vertical thrust from below. The results observed are analogous to those produced by driving a punch into a sheet of cold steel; the effects are entirely local, and the metal arches over the end of the punch until the strain is too great and the steel shatters at the point where the force is applied. Such conditions are most commonly produced by igneous intrusion, of which no direct evidence has been found in any of the numerous salt domes of the Gulf coast. It is evident from the nature and amount of the secondary minerals found in these domes (mainly salt and gypsum, which are not known in any Cretaceous formations of this area) that the forces had deep-seated connections, and it is quite probable that they were connected with igneous activity. In the early study of salt domes it was suggested that such domes were caused by igneous intrusions. Later the great thickness of salt led to the belief that the crystallization of salt may have caused the doming. Recently the trend of opinion has been toward a combination of both hypotheses.

The writer believes that forces which initiated and aided in the development of salt domes also produced the folds and faults in the areas where no salt domes are known, and that there were lines of weakness, as suggested by Harris, along which salt domes were formed by the action of dynamic forces, whereas at other places normal anticlinal folds and faults were developed. The peculiar local nature of salt domes may be due to the effect of dynamic activity at certain points along lines of deformation, aiding in the solution and transportation of salt, gypsum, etc., from deep-lying formations, probably Permian, to the position in which they are found.

POSSIBILITIES OF OIL AND GAS.

The highly folded, faulted, and eroded condition of the Palestine dome and the general absence of oil and gas as surface seepages and in shallow wells in this area detract from its oil prospects. The tilting and faulting of the rocks probably provided outlets for the escape of oil, and as no evidence of oil exists the conclusion is suggested that no large amount remains here, even if it ever accumulated. It is possible, however, that the soft and dominantly impervious nature of the formations involved in this fold closed up any possible lines of escape for the oil, as its absence at the surface may be interpreted to indicate. The eroded condition of the dome, as shown by the presence of Cretaceous rocks at the surface, and the presence of the salt core within 140 feet of the surface over a large area are also unfavorable conditions, as they eliminate the possibility that oil may be found on the crest of the dome, which might otherwise be the most favorable area for its occurrence. Oil in commercial quantities has not yet been found in a salt dome so far removed from the coast as this one.

The most likely area for the occurrence of oil, if it is present in this dome, is within a belt about half a mile wide that surrounds the area in which salt approaches within a few hundred feet of the surface, as indicated on Plate XXIII. The most favorable part of this belt is probably near its inner margin, where the underlying formations may be tilted up against the salt mass and probably end against it.

So far as observed, there are no subsidiary folds on the flank of the dome that would serve to trap upward-migrating oil; if such a trap exists it is at a considerable distance from the dome or is produced by the pinching out of a porous bed or by a fault.

A sample of gas collected from a natural escapement in Town Creek south of this dome was analyzed with the following result:

Analysis of gas from Town Creek, 1¼ miles south of the Palestine Salt Works.

[Made by the Bureau of Mines; F. M. Seibert, analyst; laboratory No. 8486.]

Carbon dioxide (CO_2)	0.5
Oxygen (O_2)	.2
Methane (CH_4)	64.7
Nitrogen (N_2)	34.6
	100.0

Specific gravity, 0.70.

Heating value (British thermal units per cubic foot at 0° C. and 760 millimeters pressure), 697.

The small percentage of carbon dioxide present in the gas suggests a deep-seated origin, whereas the absence of ethane (C_2H_5), which characterizes many but not all deep-seated gases, suggests but does not prove its surface origin. The most significant features of the gas are its high content of nitrogen and low content of carbon dioxide. Most surface gases which have as high a content of nitrogen as this one have also a much higher content of carbon dioxide.

AREA SURROUNDING THE PALESTINE DOME.

KEECHI SALT DOME.

LOCATION.

The Keechi salt dome is 6 miles in an air line west of north of Palestine and the same distance east of north of the Palestine dome. (See index map, Pl. XXII.) It is near the head of Keechi Creek, from which it derives its name. The surrounding country is rolling to hilly, and there is nothing in the topography to indicate to the casual observer the presence of a salt dome; there are no extensive salt flats or quagmires, no ring of hills, and no central depression. Some small salt licks are reported, but they are not conspicuous. The crest of the uplift probably lies near the top of a low rounded hill; Keechi Creek crosses its northern flank and a small intermittent branch crosses its south-central part, affording the most conspicuous exposures in the area. This dome has been known for many years, but no attempt was made to exploit it until 1916, when the Producers Oil Co. drilled two deep test wells; that company is at present drilling a third. During a reconnaissance examination in this country in the fall of 1916 the writer spent parts of two days investigating this dome and the surrounding area.

GEOLOGY.

This dome, like the Palestine dome, is indicated on the surface by a Cretaceous inlier, of which Dumble[1] wrote in 1890:

> Here the soil has its characteristic black waxy appearance (of *Ponderosa* clays) and exposed clays their yellow color. They contained yellow calcareous nodules and many fine specimens of *Exogyra ponderosa* Roemer, accompanied by *Gryphaea vesicularis* Lamarck. The highest beds were found to contain a decided intermixture of limestone in small fragments, below which was an arenaceous bed containing fragments of a small thin-shelled oyster of which no specimens could be secured sufficiently perfect for identication.

The area of Cretaceous clays is an open prairie, whereas that of the sandy Wilcox beds is thickly covered with post oaks, blackjacks, and pines. The exposed strata consist of the Navarro formation and the Austin chalk, which occupy the center of the dome, surrounded by the Wilcox formation; the Taylor marl may crop out but it was not recognized. The Austin chalk is represented by surface fragments scattered thickly over a few acres near the center of the W. A. Cook property, one-third of a mile north of Producers Oil Co. Barrett & Greenwood well No. 1. The Navarro formation is exposed over most of the crest of the dome. It consists of grayish-yellow lumpy clay with small white calcareous concretions and weathers to greenish yellow and finally to a sticky black soil. L. W. Stephenson has identified *Exogyra cancellata* Stephenson from a deep gully 100 yards north of Barrett & Greenwood well No. 1 and says that it represents the *Exogyra cancellata* subzone of the *Exogyra costata* zone (the lower part of the zone), which constitutes the lower part of the Navarro formation. He has also identified the following fossils, which were collected loose on the surface near the locality mentioned: *Nucula* cf. *N. eufaulensis* Gabb, *Trigonia* sp., *Plicatula* n. sp., *Crassatellites* sp., *Ringicula* sp., and *Baculites* sp. These forms, he says, probably came from the middle or upper part of the Navarro formation. The Wilcox encircles the inlier of Cretaceous and dips away from it at angles ranging from 20° to 30°. It consists of sand, sandy clay, and beds of clay, lignite, and hard sandstone. It directly overlies the Navarro formation, and the contact may be determined within narrow limits in the deep gulch below Barrett & Greenwood well No. 1, which is near the contact. The Mount Selman formation crops out 3 to 4 miles northeast, east, and southeast of this dome.

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[1] Dumble, E. T., Anderson County: Texas Geol. Survey Second Ann. Rept., p. 305, 1891.

The crest of the dome is on or near the W. A. Cook and R. R. Powers properties and is outlined by the dark plastic clays of the Navarro. On the southern slope of the dome the Navarro dips 26°–28° SE. near its contact with the Wilcox, which dips at approximately the same angle. The vertical displacement is less than in the Palestine dome, and faulting is less evident. The presence of the Austin chalk at the surface indicates that the uplift has a vertical displacement of 2,000 to 2,500 feet. The dips of the Wilcox around the dome show that it is a quaquaversal fold of probably more regularity than the Palestine dome.

DEVELOPMENT.

The Producers Oil Co. Barrett & Greenwood well No. 1 is on the southern slope of the dome, near the contact of the Wilcox and Navarro formations. It is reported to have reached the Austin chalk at 586 feet and the top of the Woodbine (?) sand at 1,686 feet; it penetrated rock salt from 2,200 to 2,900 feet, water-bearing sand from 2,900 to 2,930 feet, and rock salt from 2,930 to 3,130 feet, at which depth it was abandoned. The Woodbine (?) sand yielded 1 or 2 barrels of heavy tarry oil at 1,686 feet. A second well was drilled on the same lease, 1,000 feet east of south of the first. The Austin chalk is reported in this well at about 1,400 feet, and the Woodbine (?) sand, which yielded salt water that could not be bailed below 500 feet, at 2,297 feet. The dip from the first to the second well, as indicated by the Woodbine sand, is about 35°. The possibility of finding oil in this dome is considered better than in the Palestine dome because it appears to be less faulted, the salt core does not come so close to the surface, and the Woodbine (?) sand is within reach of the drill and also deeply enough buried to have retained its oil.

ELKHART.

Two miles southeast of Elkhart, along the International & Great Northern Railroad, the normal southeasterly dip is interrupted by reverse dips of a fraction of a degree to 1° NW. Four miles southeast of Elkhart a fault with a northeast trend and an indeterminable throw is exposed in a railroad cut. It is not known whether the reverse dips observed are due to this fault or whether the fault is incidental to a fold trending northeast which produces the reverse dips. The evidence gathered from a day's visit to this area suggests the presence of considerable deformation there.

One mile northwest of Elkhart, in the bottom of a branch on the southwest side of the railroad, a fault that is probably of considerable throw strikes N. 38° E. and dips 58° NW. This fault is near the south line of the William Frost survey. The beds are essentially the same on the two sides of the fault; on the east, the upthrown side, they dip gently to the northwest, and on the northwest side they dip locally in the same direction but at a much higher angle, showing the effect of the downward drag on that side. About 100 yards southeast of the fault the beds become practically horizontal for a few hundred yards, and beyond that they dip gently to the southeast.

Southwest of this locality, along the supposed continuation of this fault, 1¼ miles southwest of Elkhart, a dip to the northwest is observed in the banks of a small branch for a distance of several hundred yards. Here a hard bed of ferruginous shell marl is overlain successively by green lumpy clay with veins of gypsum and brown carbonaceous clay, and all dip progressively beneath the creek bed upstream. Farther upstream there are irregularities in the dip of the beds and clear evidence of faulting. This disturbance in the normal southeastern dip of the beds is probably connected with the fault described above and may have caused the asphalt seeps west of Jarvis that are described on the following pages. The deformation observed here may be sufficient to produce favorable structural conditions for the accumulation of oil and gas. Although the area was not studied in sufficient detail to ascertain the most favorable places to test it with the drill, a well near the east side of a line connecting the two localities described would be more favorably situated than the average wildcat wells, located with less regard for structure.

JARVIS.

Near Fields Chapel, half a mile northwest of Jarvis and about 12 miles east of Palestine, asphaltic sand crops out 100 yards north of the road, where a shallow well was dug, and in the road at three localities west of the chapel. The asphaltic sand is medium grained and irregularly bedded. Its pore space is filled with black asphaltic oil, which oozes out on the surface in warm weather. The shallow well showed the following section:

Log of well on M. A. Davey farm, near Jarvis, Anderson County, Tex.

	Feet.
Soil impregnated with asphalt; runs slightly in warm weather	½
Clay, hard, laminated	1½
Sand, asphaltic	1
Clay, hard, laminated	3
Sand, hard, asphaltic	2½
Clay, as above, but containing streaks of asphalt along bedding planes and joints	4
Sandstone, asphaltic	3
Clay, laminated, streaked with oil	5
Sandstone, hard and dry, but shows asphalt when treated with gasoline; about 2 tons used to patch street in Palestine	4
Sand, coarse, white, becoming damp	3
	27½

The brief inspection of this area did not show conclusively whether the asphalt indicates the outcrop of an oil-bearing sand or the presence of a fault that has allowed the upward migration of the oil from below. The evidence is in favor of the latter.

Mr. Davey drilled a well 1 mile northwest of Jarvis on the north side of the Palestine road to a depth of 1,300 feet. It shows considerable heavy black oil and is said to have flowed a stream of water when it was drilled. There is a seep of oil in the branch near by, and on the opposite side, to the west, Mr. Nemer, of Palestine, drilled a well to a depth of 700 feet without any significant results.

WELLS CREEK DISTRICT.

Twelve wells have been drilled by local companies in search of oil near Wells Creek, 4 miles south of Neches and about 12 miles northeast of Palestine. Most of these wells were drilled in the valley of Wells Creek near the crossing of the Alderbranch-Neches road. The deepest well was drilled by Mr. Granberry about six years ago on the north side of the creek to a depth of 2,500 feet; most of the other wells reached depths of 800 to 1,500 feet. Oil of 17° to 18° Baumé was found at about 864 and 1,010 feet, according to M. A. Davey, in the wells near the road crossing; a flow of sulphur water was found there at about 700 feet, and below the oil fresh water was found. The best showing of oil was found in the wells west of the Alderbranch-Neches road and on the south side of Wells Creek. Some of the wells only a short distance up the creek are said to have shown no oil. The rock exposures in this area are very poor, and it is considered difficult, if not impossible, to determine the local structure from surface outcrops.

POSEY SALINE.

The Posey saline is on the west side of Neches River, about 1 mile north of Stills Creek and 15 miles east of Palestine. It is marked by a flat, open prairie covering an area along the river of about 250 acres, which is dotted here and there by scalds, areas barren of vegetation, quagmires, soft wet boggy areas, and ponds. The evaporation of water leaves an incrustation of salts on the surface in certain areas. A large sulphur spring (Big Sulphur Spring) issues near Stills Creek, 1 mile southwest of the saline. It is in a low swampy area and flows a bold stream of water highly charged with hydrogen sulphide gas, which decomposes at the surface, causing the precipitation of quantities of white amorphous sulphur. A similar but smaller sulphur spring (Little Sulphur Spring) issues near the northeastern edge of the saline, on the bank of Neches River. Half a mile northwest of Little Sulphur Spring is the so-called soda spring, where, it is reported, soda was made by evaporating the water during the Civil War. North of the saline is an "island" or mound in the low land along Neches River. It is a comparatively small, flat-topped area about 6 to 8 feet above the bottom land. It is cut off from the high land by a slough that represents an old channel of Neches River. The "island" is a remnant of a terrace slightly elevated above the present river bottom. The salt incrustations formed at this saline consist of a mixture of alkaline carbonate and alkaline chloride.

This is a typical saline, but so far as surface evidence shows it is not a salt dome, as the strata in the surrounding area are not highly disturbed and there is nothing in the topography to suggest an uplift. The peculiar features of the saline are due to the presence of mineralized water. It is likely that this saline is situated near a fault which permits mineralized waters to reach the surface. If there has been any doming of the strata there, it was completed prior to the deposition of the surface formation, which belongs to the Claiborne group.

THE BRENHAM SALT DOME, WASHINGTON AND AUSTIN COUNTIES, TEXAS.

By Oliver B. Hopkins.

INTRODUCTION.

The discovery of heavy, tarlike oil in a shallow water well near the Washington-Austin county line, 9 miles southwest of Brenham (see Pl. XXII) led to drilling for oil there. A local company, the Brenham Oil Co., was formed and in the spring of 1915 drilled a well that showed such favorable indications of oil and gas that a second well was drilled, and this has yielded 4 to 6 barrels a day for almost two years. The completion of this small well led to the leasing of large areas in the vicinity and started the drilling of 12 additional wells, making altogether 14 that have been drilled to the present time (April, 1917). With the exception of the small oil well and the discovery of gas in another well, which "blew out" and finally became choked, the results of the drilling have been discouraging, except that they have demonstrated the presence of a salt dome.

At the request of residents of the vicinity of Brenham, who were interested in the development of the area and who volunteered to furnish all the available well logs and samples for study, an investigation was undertaken by the United States Geological Survey to determine whether the structure of the area could be determined from surface study and from the well records and whether any geologic assistance could be given in the development of the area. The results of the studies have been largely disappointing, as they fail to throw much light on the probable presence and location of oil there. It is hoped, however, that the information set forth here may be of value to those who may continue drilling in this area.

LOCATION AND TOPOGRAPHY.

The Brenham salt dome lies along the Washington and Austin county line, 9 miles southwest of Brenham and about 70 miles northwest of Houston, Tex. It is most easily reached from Brenham, which is on the Atchison, Topeka & Santa Fe and Houston & Texas Central railways.

The country is a rolling prairie with a general altitude of 300 to 450 feet above sea level. The hills are mostly grass covered and treeless and have gentle rounded slopes. The structural dome is situated between the valleys of Williams and East Mill creeks, and although its crest is believed to occupy high ground, it does not occupy the highest ground in the area, probably because of its proximity to the two creeks mentioned. Topographically it is not a conspicuous feature, like the "mounds" on the low, flat prairie near the coast, although the details of the drainage may suggest to the trained observer the presence of a salt dome.

GEOLOGY.

SURFACE GEOLOGY.

The Brenham salt dome (Pl. XXIV) is near the middle of a belt of the Lagarto clay, which extends southwestward from Brazos River past Brenham and Cuero to and a short distance beyond San Antonio River.[1] A partial list of the geologic formations that lie below the Lagarto clay is given in the accompanying table.

The Lagarto clay consists dominantly of clay and sandy clay, which are gray or green when fresh and which weather into a black plastic clay, and lenticular beds of cross-bedded sand and soft sandstone. The cross-bedding and lenticularity of the beds make the structure of the area in which they crop out difficult or impossible of determination. There are chalky beds and beds with numerous chalky concretions which may be traced short distances where the rock exposures are exceptionally good. Outcrops of this formation surround the Brenham dome and cover its entire area, with the possible exception of a few small exposures of coarse-grained pebbly sand with waterworn Cretaceous fossils in the bed of Williams Creek, one-third of a mile south of the center of drilling operations. This sand may represent the base of the Lagarto clay or the top of the underlying Oakville sandstone. Deussen[2] reports that near Halstead, 6 miles east of LaGrange, at the base of the Lagarto clay, which rests unconformably on the Oakville standstone, there is a bed of gravel with worn Cretaceous shells. It is possible that these exposures represent the same beds, which are elevated in the area of this dome sufficiently to bring them to the surface where normally they would be several hundred feet below it.

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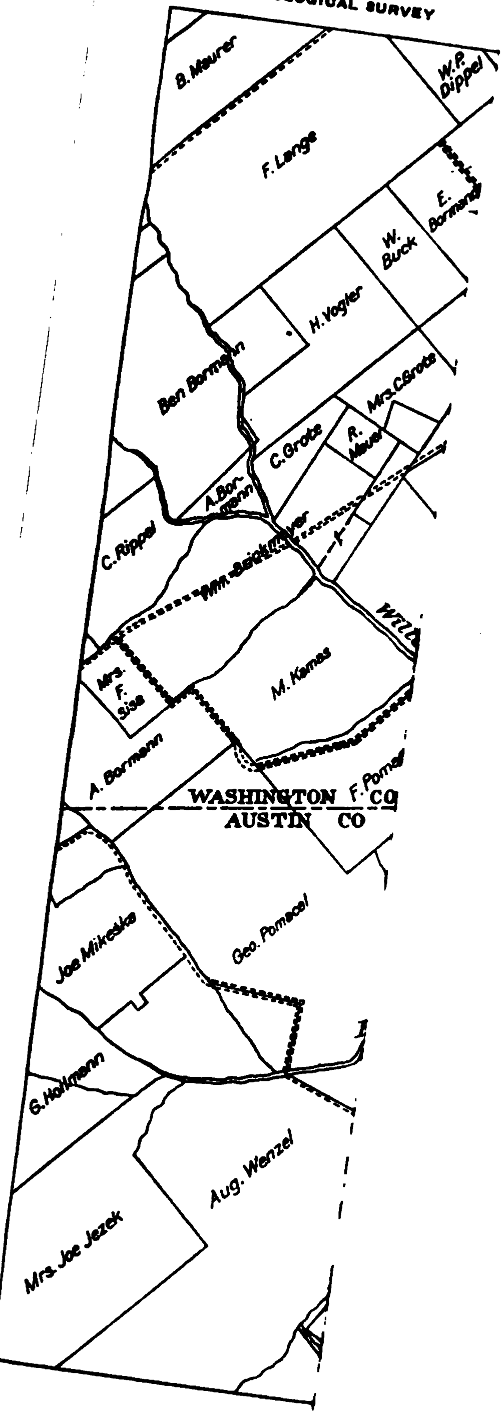
[1] The distribution of this formation is stated as shown on an unpublished map of the Coastal Plain of Texas west of Brazos River, by Alexander Deussen.

[2] Deussen, Alexander, op. cit.

U. S. GEOLOGICAL SURVEY



Partial geologic section exposed in the Coastal Plain of Texas west of Brazos River.[a]

System.	Series.		Formation.	Thickness.	Lithology.
Tertiary.	Pliocene.		Lagarto clay.	*Feet.* 200-400	Clay with lime concretions and calcareous cross-bedded sand. Clay light-colored or green when fresh, black on weathering.
			Lapara sand.[b]	50-100	Sand and clay, interbedded; clay red, green, and pink.
	Miocene.		Oakville sandstone.	200-300	Sandstone, gray, soft, calcareous in places; some clay lenses.
	Oligocene.		Catahoula sandstone.	200	Sandstone, hard, blue, quartzitic; green, blue, brown, and white clay; and gray cross-bedded sandstone.
	Eocene.		Frio clay.	500	Clay, green and pink, with small lime nodules; beds of volcanic ash; beds of brown marl in lower part.
			Fayette sandstone.	800	Sandstone and sand, gray; brown and lignitic clay; volcanic ash and white kaolin-like clay.
		Claiborne group.	Yegua formation.	600-720	Clay, dark green and brown, lignitic; sand, yellow and dark colored; lignite.
			Cook Mountain formation.	700-800	Greensand, greensand marl, iron ore, lignite, lignitic clay, clay, sandstone, and sand. Glauconitic sand and clay predominate.
			Mount Selman formation.	600-700	Sand, dark green and brown; thin seams of iron ore; lenses of lignite and clay; beds generally iron bearing.
			Carrizo sandstone.	200-450	Sandstone, coarse grained, cross-bedded, calcareous in part; coarse quartzitic sand and fine-grained micaceous sandstone.
			Wilcox formation.	350-650	Sand lenses, sandstone, clay, sandy clay, and lignite.
			Midway formation.	260	Clay and limestone of marine origin.
Cretaceous.	Gulf (Upper Cretaceous).		Navarro formation.	500-600	Marl, bluish black, and glauconitic clay; blue clay with siderite and limonite concretions; yellow and brown sand with hard sandy concretions.
			Taylor marl.	600-700	Clay marl, blue, calcareous. West of Bexar County the Taylor marl is replaced by the Anacacho limestone.
			Austin chalk.	304-500	Chalk, interstratified with thin beds of soft marl.
			Eagle Ford shale.	21-200	Shale and thin arenaceous beds of laminated limestone.

[a] From manuscript report by Alexander Deussen on geology of Coastal Plain of Texas west of Brazos River.

[b] This formation is absent in the area near the Brenham dome.

UNDERGROUND GEOLOGY.

The knowledge of the underground geology in the area of the Brenham dome is obtained from the 14 wells that have been drilled there. The character and thickness of the beds penetrated in these wells are shown in Plate XXV, which shows five representative well records, arranged roughly in an east-west line across the dome. It is not possible to divide the beds as shown in the well records into the formations that have been recognized at their surface outcrops, as the materials lack distinctive features.

Shells submitted by Alexander Deussen from the Brenham Oil Co.'s well No. 1 (Schuerenberg lease), from a depth of 1,275 to 1,360 feet, were examined by C. W. Cooke and identified as probably of Cook Mountain age. A larger collection from this well at a depth of 1,294 to 1,319 feet was determined by C. L. Baker as of Cook Mountain age, thus proving that that formation had been reached. Mr. Baker also recognized the greensand marl found at 1,600 feet in the Gulf Production Co.'s No. 1 Thielmann well as Cook Mountain. Other fossils of Claiborne (Eocene) age were identified by Mr. Baker from the Brenham Oil Co.'s well No. 2, and from the Milam Oil & Gas Co.'s well No. 1.

The minimum thickness of the formations between the base of the Lagarto clay and the Cook Mountain formation is, according to Deussen, 2,300 feet, and as the wells here start in the Lagarto and reach the Cook Mountain at 1,300 to 1,600 feet, either the intervening formations must be locally much thinner than the normal or some of them must be absent, a condition which suggests the uplift and erosion of this area between the periods of deposition of the Cook Mountain and Lagarto formations.

Brown gumbo and streaks of lignite, which may belong to the Yegua formation, were found in well No. 1 of the Brenham Oil Co. at a depth of 861 to 996 feet, in No. 2 at 1,027 to 1,067 feet, in No. 3 at 1,262 to 1,282 feet, and in well No. 1 of the Kamas Oil Co. at 905 to 932 feet. The Brenham Oil Co.'s well No. 4 penetrated gypsum (largely anhydrite) from 1,113 to 1,500 feet, and sand and some gypsum from 1,500 to 1,587 feet.

Gray sandy clay, secondary (?) limestone, and gypsum are reported from the Brenham Oil Co.'s well No. 5 at a depth of 1,360 to 1,395 feet, also a salt-water flow, which was not reported from any of the neighboring wells.

The second test of the Gulf Production Co. (not numbered) was abandoned at 1,296 feet in a porous rock which absorbed the return fluid and made deepening impossible.

Gypsum was reported from the Gulf Production Co.'s well No. 2 (Schuerenberg tract) at depths of 1,303 to 1,312 and 1,354 to 1,392 feet, and rock salt at 1,392 to 1,442 feet. Numerous fragments of cuttings from the slush pit of this well were tested and found to be chalk. However, the absorption of the return fluid by the beds at depths near 1,442 feet, the depth at which the well was abandoned, indicates clearly that the core of secondary minerals of the salt dome had been reached. Returns were also lost in the Kamas Oil Co.'s well No. 1 at different levels from 1,185 to 1,390 feet, where the well was abandoned. It is likely that the rock reported from these intervals is secondary limestone or gypsum.

The secondary limestone, gypsum, and salt are typical of salt domes, and their presence in this area indicates the presence of a dome of that type. Drilling indicates that the core of secondary minerals comes nearest to the surface on the Kamas, Sundehusen, and Schuerenberg tracts, which may represent approximately the center of the uplift.

Fresh, potable water was abtained in a well a short distance west of the Milam Oil & Gas Co.'s well No. 1 at a depth of 525 feet.

EVIDENCE OF SALT DOME.

The evidence of a salt dome in this area includes (1) the presence of Cook Mountain fossils 600 to 900 feet nearer the surface than is normal for this area, (2) the marked differences in the strata found in neighboring wells, (3) the apparent discordance in the dip of the surface and underlying beds, (4) the presence of shallow oil, (5) the presence of porous beds that absorb the return fluid and make drilling difficult or impossible, and (6) the occurrence of secondary limestone, gypsum, and salt (?). As examples of the marked differences in the character of the strata encountered in neighboring wells may be mentioned the salt water found in the Brenham Oil Co.'s well No. 5 and not in any of the surrounding wells; "quicksand," which caused the abandonment of the well, found in the second test boring of the Gulf Production Co. and not found in that company's well No. 2 near by; and gypsum found in Brenham No. 4 and not in neighboring wells at the same depth. The occurrence of porous material, such as limestone or gypsum, in which the returns are lost, is good evidence of the presence of a salt dome.

STRUCTURE.

A study of the surface outcrops around the Brenham dome shows that the beds have not been highly deformed but dip gently away from the center of the uplift. This is particularly noticeable on its north side, where the exposures are best. Because of the obscurity and scarcity of exposures and because the principal folding had taken place prior to the deposition of the surface formation, the shape and extent of the uplift can not be determined from surface study. Fossils from wells drilled here show that the Cook Mountain formation is reached at about 1,300 feet, near what is considered the center of the uplift, whereas this formation should normally be about 2,000 to 2,200 feet below the surface and has therefore been uplifted 600 to 900 feet. It is evident that this formation dips away steeply from the crest of the uplift and that there is a wide discordance in dip between the Cook Mountain and the surface formation. It is impossible to correlate with certainty the beds represented in the well logs and thus to determine the amount of dip. If the shallow oil sand found at about 100 feet in nearly all the wells near the center of development is the same in the different wells, the results are entirely consistent; the dip is 160 feet to the mile to the east from the Brenham Oil Co.'s well No. 4 to the Milam Oil & Gas Co.'s well No. 1; 207 feet to the mile from the Brenham Oil Co.'s well No. 4 to No. 3; and 244 feet to the mile from the Brenham Oil Co.'s well No. 4 to the Gulf Production Co.'s well No. 2. These figures suggest that the dip is to the northeast, east, and southeast from Brenham well No. 4, which may be near the center of the uplift. If the oil sand in Brenham well No. 1 is the same as in No. 2 the dip is to the south at about 900 feet to the mile. This may or may not be the correct dip.

A tentative correlation of the lignite and brown shale was made, but the results did not harmonize with the supposed facts, and they are therefore believed to be unreliable for the determination of the structure.

The folding associated with salt domes is so intense that regular quaquaversal structure is in most places much complicated by faults. It is therefore difficult and usually impossible to outline even the major structural features of a salt dome without numerous records of well-distributed borings. Such records are not yet available for this dome. It seems likely, however, that the crest of the dome is near well No. 4 of the Brenham Oil Co., which penetrated several hundred feet of gypsum, although possibly, as this well penetrated sand below the gypsum, it is not on the crest, and the gypsum found here is a tongue projecting from the main mass. The supposed center of the dome is indicated on the accompanying map. The wells within the area shown encountered either gypsum or some porous stratum that absorbed the fluid in the hole and prevented any returns reaching the surface.

Deussen[1] pointed out that this dome is in a general line connecting the Steen dome east of Lindale, the Brooks dome west of Bullard, the Keechi and Palestine domes in Anderson County, and the Butler dome southeast of Butler. This line roughly parallels the Balcones fault.

WELLS DRILLED.

BRENHAM OIL CO.

Well No. 1 (on Schuerenberg lease), drilled in 1915 to depth of 1,451 feet. Shallow oil reported at 108–112 feet; deep oil sand at 1,319–1,328 and 1,438–1,451 feet. Six-inch casing set at 1,320 feet. Well dry but made showing of oil and gas.

Well No. 2 (on Schuerenberg lease), depth 1,372 feet. Oil sand reported at 1,358–1,361 and 1,363–1,372 feet. Well pumped for about two years; yields

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[1] Deussen, Alexander, op. cit.

4–6 barrels of oil of 40°–41° Baumé. This was the only productive well in the field in 1916. No secondary minerals were recognized in the cuttings.

Well No. 3 (on Kramer lease), drilled in 1915, and abandoned at depth of 1,686 feet in shale. Shallow oil found at 122–123 feet. No promising indications were found in the lower beds.

Well No. 4 (on Sundehusen lease), depth 1,587 feet. Encountered shallow oil at 98–104 feet and penetrated gypsum (largely anhydrite) from 1,113 to 1,500 feet. Yielded a flow of mineralized water at 1,587 feet.

Well No. 5 (on Schuerenberg lease), depth 1,395 feet. Encountered shallow oil at 104–140 feet, salt water at 1,376 feet, and probably secondary limestone and gypsum at 1,360–1,395 feet.

CALHOUN OIL CO.

Well No. 1 (on H. A. Lehman lease); no information available concerning this well.

GULF PRODUCTION CO.

Well No. 1 (on Thielmann lease), drilled in 1915 to depth of 1,694 feet. Shallow oil found at 108–120 feet, Cook Mountain fossils at 1,600 feet. Well blew out at about 1,573 feet and raised the 4-inch drill stem out of the well but became choked within a few days. Showing of oil and gas reported at 1,576–1,578 feet. This well yielded more gas than any other in the area.

Lost hole (on Schuerenberg lease, well not numbered), depth 1,296 feet. Cook Mountain fossils identified by J. A. Udden from depth of 1,140–1,150 feet. "Quicksand" near bottom which absorbed returns and caused the hole to be abandoned.

Well No. 2 (on Schuerenberg tract), depth 1,442 feet. Gypsum reported at 1,303–1,312 and 1,354–1,392 feet, and rock salt at 1.392–1,442 feet. Lower beds absorbed returns. No gypsum found in the slush pit.

MILAM OIL & GAS CO.

Well No. 1 (on Kramer lease), depth 1,756 feet. Showing of heavy oil at 104–107 feet, salt water at 1,686–1,693 feet. No indications of importance found.

KAMAS OIL CO.

Well No. 1 (on Kamas lease), drilled in 1915, abandoned January, 1916; depth, 1,390 feet. Returns lost between 1,190 and 1,390 feet, probably in porous gypsum or cavernous limestone.

LEHMANN OIL CO.

Well No. 1 (on Lehmann lease), depth 1,933 feet. Lignite reported at 1,786–1,790 feet. No secondary limestone or gypsum found; no indications of importance.

RADKE OIL & GAS CO.

Well No. 1 (on Radke lease), drilled by Badgett & Mulloy; depth 1,700 feet. Cuttings mostly loose gray sand and pink and green clay. Well flows small stream of fresh water; no showing of oil or gas reported.

STAMMANN OIL & GAS CO.

Well No. 1 (on L. Stammann lease), drilled and abandoned in 1915; no casing set; depth 1,500 feet. Showing of gas reported at 1,030 and 1,226 feet.

OCCURRENCE OF OIL.

In the Brenham dome tarlike oil has been found in small quantities at a depth of about 100 feet in most of the wells on and near the F. W. Schuerenberg lease, and in the same area oil has been found at depths of 1,319–1,451 feet in the Brenham Oil Co.'s well No. 1, and at 1,358–1,372 feet in well No. 2 of the same company.

Well No. 2 has yielded 4 to 6 barrels of oil a day for about two years. The oil is dark green, has a gravity of 40°–41° Baumé, and when freshly pumped is fairly liquid. On standing in an open tank a few days it loses a considerable part of its volatile constituents, and when cooled to 35° to 40° F. it solidifies, and a layer of semisolid oil, like axle grease, forms on the surface. On standing in a sealed bottle the heavy constituents settle to the bottom.

The heavy oil found at about 100 feet is probably in the Lagarto clay or possibly in the Oakville sandstone. As these formations are not known to contain oil at any locality and are not known to be bituminous, it seems likely that this oil has seeped upward from some underlying formation, although it is difficult to explain why some of the underlying sands do not show oil, and particularly why the sand at 525 feet, which yields fresh, potable water, has not been polluted by such an upward migration.

The evidence from fossil shells shows that the oil in the deep sand comes from the Cook Mountain formation, which has yielded a small quantity of oil at Oil City, Nacogdoches County, and at Crowther, McMullen County. It seems probable, therefore, that the oil in the Cook Mountain is indigenous. If this inference is true, it has an important bearing on the problem of the possible discovery of commercial pools of oil here.

The table on page 273 shows the position, lithology, and approximate thickness of the formations above and below the Cook Mountain. The oil from the salt domes of the coastal region of Texas—Humble, Sour Lake, Batson, and others—is believed by many geologists to come from sands above the Cook Mountain. If this is true, the sands which are oil bearing in those domes will probably not be so in this area, as these sands have been penetrated by a number of wells here without promising results. The Navarro formation is the next known oil-bearing formation below the Cook Mountain. The intervening beds, however, contain much sand and carbonaceous matter at their outcrops, and it is quite possible that some one of them may be found to contain oil under favorable structural conditions, such as probably exist here. The Nacatoch sand member of the Navarro formation yields gas in the Mexia-Groesbeck field and oil in the Corsicana field. If the thicknesses given on Plate XXV are applicable to this area, the Navarro may be reached here at about 3,500 feet.

However, faults and unconformities within the intervening formations, such as are indicated in the Palestine and Keechi domes, in Anderson County, may make any estimate unreliable. It is not known whether the Navarro is petroliferous in this area, or even whether it contains sand here.

According to some geologists, the oil in the salt domes of the coast is adventitious and is derived through faults from underlying formations, probably of Cretaceous age. If this is true, it is probable that oil may be found here under similar conditions. Oil is commonly found in porous limestone, or in sands overlying or tilted up against the salt core. The overlying sands in the Brenham dome have been drilled through at several places and yield a small quantity of oil in well No. 2 of the Brenham Oil Co. It seems doubtful whether these sands, which appear to be thin, contain oil in commercial quantities on or about this dome. The porous limestone also has been reached in several wells, notably in Kamas Oil Co. No. 1; but as it has not yielded oil in any of the wells, its possibilities are not encouraging. Below the porous secondary limestone, the "cap rock," gypsum is commonly found, and salt below that. This being true, it is probably useless to drill deeper when the limestone is reached and the general succession of materials is established. The remaining possibility is to find oil in sands or other porous beds tilted up around the flanks of the salt core. Oil is found at Humble both in the "cap rock" and in steeply inclined sands on the flank of the dome. The absence of oil in the "cap rock" in the Brenham dome does not necessarily mean that oil will also be absent in the surrounding sands, although it suggests that possibility.

SUGGESTIONS REGARDING FURTHER DRILLING.

If the inferences set forth in the preceding paragraphs are well founded, the sides and not the crest appear to be the most favorable parts of the Brenham dome for oil. A number of wells have already penetrated the sediments overlying the central mass of limestone and gypsum, and some have penetrated parts of the limestone with unfavorable results. If more wells are drilled they should be located on the flank of the dome, where the drill will miss the central core of secondary limestone and gypsum and will penetrate older beds below the Cook Mountain formation, as shown in Plate XXIV. It is possible that tongues of limestone and gypsum, which may be easily penetrated, may extend into the sedimentary beds from the central core. Such tongues may have been reached by Brenham Oil Co.'s well No. 4, which encountered sands below several hundred feet of gypsum. There is no good geologic reason why this well should not have been deepened so long as it did not encounter the central core of gypsum.

It seems unlikely that a deep test boring within the area marked "supposed center of uplift" on the accompanying map would be successful, as it would probably encounter the central core of limestone and gypsum at 1,000 to 1,200 feet. Although the shape and size of this core have not been determined, it is believed that wells located on the south or southeast side of the uplift and within 1,000 to 2,000 feet from the outline of the supposed center of uplift would have the best prospects for success. Wells here would probably reach the Cook Mountain formation at a somewhat greater depth than on the crest of the uplift, and deeper drilling than has been done will be necessary to test this area.

In the Brenham dome, as in most other salt domes, drilling is attended with many uncertainties and should not be undertaken without full knowledge of them. Failure to find oil in commercial quantities in the porous limestone, the "cap rock," and the sands overlying the crest of the dome makes deeper drilling necessary, with its increased costs and risks.

OIL AND GAS POSSIBILITIES OF THE HATCHETIGBEE ANTICLINE, ALABAMA.

By OLIVER B. HOPKINS.

INTRODUCTION.

During 1884–85, 16 years before the discovery of oil at Beaumont, Tex., a well was drilled near Bladon Springs, Ala. (See description of Cullom Springs well, p. 310.) This was one of the earliest deep wells drilled for oil in the Gulf Coastal Plain. The reasons that led to the selection of this area as a possible oil field are not known, although it is interesting to note that this well was drilled near the crest of the Hatchetigbee anticline at a time when the anticlinal theory of oil and gas accumulation was being much discussed. A small showing of gas was found in this well, but the results were not regarded as sufficiently promising to encourage further exploration, and the region seems not to have attracted any further attention until after the discovery of oil at Beaumont in 1901.

The discovery of oil in the famous Lucas "gusher" at Beaumont and the recognition of the association of oil with salt domes in the Gulf coastal region led to extensive drilling in areas where the presence of salt domes was suspected. As salt springs and salt wells in the area of the Hatchetigbee anticline had been known since before the Civil War, this area came immediately into prominence as a possible oil and gas field. From 1902 to 1905 or 1906, six fairly deep wells were drilled here. Although Smith[1] and others had published in 1894 a description and a generalized map of the Hatchetigbee anticline, these wells were poorly located with reference to the structure, and all were drilled near old salt wells or springs. Since 1906 little drilling has been done in this area, although interest in the possible occurrence of oil and gas here has survived, and from time to time leases have been taken and development work projected. At the time the field work on this report was being done geologists employed by several oil companies were making a reconnaissance examination of the area, and soon after the Survey's field work was completed leasing was begun near Bladon Springs.

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[1] Smith, E. A., Johnson, L. C., and Langdon, D. W., jr., On the geology of the Coastal Plain of Alabama, Alabama Geol. Survey, 1894.

Most of the wells referred to above yielded small quantities of gas, but it is not definitely known whether any of them yielded even a trace of oil. Many of the residents of the country assert that they saw oil coming from some of these wells. It is also reported that while a channel was being blasted out in Tombigbee River at McGrews Shoals, near St. Stephens, oil in considerable quantities seeped from the rocks in the river bottom.

The present interest in the oil and gas possibilities of this area, however, is not due to the occurrence of salt or gas in shallow wells or to the results of the drilling operations described above, but to the work of E. A. Smith and others, who outlined a large, well-defined anticline in this area, and to the knowledge that the most favorable areas in which to look for commercial pools of oil and gas are along the crests of such folds. The object of the present work is to show more in detail the location and extent of this anticline, to point out in a general way the areas that are most deserving of tests with the drill, and to give those interested in exploratory drilling for oil and gas information regarding the geology of the area, the character of this fold, and the occurrence and depth of possible productive oil sands.

SUMMARY.

The geologic examination of the area shows that a broad, low anticline, the Hatchetigbee anticline, extends from a point north of Jackson, Ala., northwestward across Tombigbee River to the Alabama-Mississippi State line and beyond; that the disturbance of the earth's crust which produced this fold also produced a fault, the Jackson fault, which extends from the southeast end of the anticline in a southeasterly and southerly direction past Jackson and the Central Salt Works to the Lower Salt Works near Oven Bluff, on Tombigbee River; that the Hatchetigbee anticline has in general stronger dips on its southwestern slope than on its northeastern; that two areas along the crest of the fold are particularly favorable, structurally, for the accumulation of oil and gas, and other areas along the crest of the fold and along the east side of the Jackson fault are also favorable; that the best chances for accumulations of oil are probably in the sands above and below the Selma chalk, which lies from 780 to 2,700 feet below the surface along the crest of the anticline; and finally that there are doubtless other areas of favorable structure in the adjoining region where oil and gas may have accumulated if they are present in commercial quantities anywhere in the region.

FIELD WORK.

The field studies on which this report is based were made by the writer, without assistance, in seven weeks during November and

December, 1916. The report by E. A. Smith,[1] State geologist, on work in this and adjoining areas was used as a guide to the general geology and structure of the region. The most detailed studies were made of the areas described by Smith under the headings "Hatchetigbee anticline" and "Other Buhrstone displacements."[2] In order to ascertain somewhat in detail the structure of these areas, the general distribution of the rock formations was outlined, the direction and rate of dip of the rock beds were determined wherever possible, and as much other information relating to the general geology and structure was obtained as was possible during a reconnaissance survey.

The progress of the work was much hampered by the lack of sufficiently detailed maps on which to plot the field observations, by the difficulty in making correct locations on the available maps, and by the scarcity of bench marks or points of known altitude in the area. Wherever possible the locations made on the maps were verified by inquiry among the residents as to the position of section lines, section corners, and land lines. In this way many exact locations were made with regard to land and section lines, and some of the most conspicuous errors in the maps were corrected. The application of this method of location was not satisfactory in many parts of the area that are sparsely settled, because much of the land is farmed by renters, many of whom are not cognizant of the position of property and section lines.

Altitudes were determined with an aneroid barometer from bench marks established by Army engineers along Tombigbee River over the area studied and were corrected from barograph records. As there are a number of easily recognized beds in the area, the most satisfactory method of determining the direction and rate of dip was by comparing altitudes on these beds at different points. Dips were also determined directly with a clinometer and, where the exposures were long enough, by a direct measurement of the difference in altitude of a bed at two points and the distance and direction of one of these points from the other.

Satisfactory key rocks are most easily recognized in the Vicksburg and Jackson formations, which crop out on the flank of the fold, whereas it is difficult to recognize individual beds in the Hatchetigbee, Tallahatta, and Lisbon formations, which crop out near the center of the uplift. Within the Tallahatta formation, however, there are many hard ledges from which the dip of the beds may be determined.

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[1] Op. cit.

[2] Op. cit., pp. 211-226.

ACKNOWLEDGMENTS.

The writer is indebted primarily to Dr. E. A. Smith, who was the first to study this area and to outline its general structure, both for the information contained in his published reports[1] and for his helpful suggestions during the course of the field studies. Dr. Smith furnished an unpublished sketch map of the area near Jackson, made under his direction by Mr. S. A. Hobson, which shows the general distribution and relations of the different formations. Although the writer disagrees with Dr. Smith and Mr. Hobson in their interpretation of the structure of the area, this map was of great service.

He is indebted also to Mr. C. W. Cooke, of the United States Geological Survey, for the results of his studies of the Vicksburg and Jackson formations in southwestern Alabama, to which he had access before they were published, for information given informally regarding the characteristic fossils of the different formations, and for the identification of a number of small collections of fossils that were used to check the results given herein. The separation of the "St. Stephens limestone" into the Vicksburg and Jackson formations is based on the paleontologic studies of Mr. Cooke.

The writer also wishes to express his appreciation to Mr. L. W. Stephenson, who has made a special study of the Cretaceous of the Gulf coastal region, for suggestions regarding the buried Cretaceous deposits of this area; to Mr. W. B. Bolinger for a blue-print map of southern Choctaw County; and to many citizens of the area for numerous courtesies and assistance in showing him section and land lines and obscure rock exposures.

LOCATION OF THE AREA.

The area described in this report lies in southwestern Alabama. It extends from the Alabama-Mississippi State line southeastward to and beyond Jackson, on Tombigbee River, including the southern part of Choctaw County, the northeastern part of Washington County, and the southwestern part of Clarke County. The exact location and extent of the area examined is shown on Plate XXVI. It is about 40 miles long from northwest to southeast and 12 to 15 miles wide from northeast to southwest. The largest towns within the area are Jackson, Salitpa, Bladon Springs, and Silas. It is most easily reached over the Mobile-Selma branch of the Southern Railway, which runs through Jackson, or over the Mobile-York branch of the Alabama, Tennessee & Northern Railway, which runs through Silas. Birmingham, Montgomery, Mobile, and New Orleans are the nearest large cities.

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[1] Smith, E. A., Johnson, L. C., and Langdon, D. W., jr., On the geology of the Coastal Plain of Alabama, Alabama Geol. Survey, 1894. Smith, E. A., The underground water resources of Alabama, Alabama Geol. Survey, 1907.

TOPOGRAPHY.

Viewed broadly, the area of the Hatchetigbee anticline is a somewhat dissected plain, with a general altitude of 150 to 250 feet above sea level, dipping gently seaward. Few prominent hills rise above this widespread plain, and in it the streams have cut their valleys. One-half to three-fourths of the area is timber covered, long-leaf pine predominating in the uplands and hardwood trees in the lowlands. Viewed more narrowly, this area is seen to exhibit three distinct types of topography—the broad, flat valleys of Tombigbee River and its tributaries; the high, flat terrace lands; and the rough, much dissected hilly areas.

The lowlands along Tombigbee River, which traverses the central part of the area, range in altitude from 30 to 50 feet above sea level and in width from 2 to 5 or 6 miles. Large areas of these lowlands are subject to overflow, are uncultivated, and are covered with swamps and forests of hardwood trees. The streams that flow into the Tombigbee also have broad, flat valleys, whose gradients are so low that few of them attain an altitude of 80 feet within 5 miles of the river. Near their sources these streams are actively sinking their channels, but in the lower parts they meander through broad valleys. Near the mouths of many of these streams there are open palmetto flats, but in general they are bordered by thickets of underbrush and hardwood forests.

From the lowlands along the Tombigbee and its tributaries the hills rise steeply to altitudes of 150 to 250 feet. Much of this upland in the southern and particularly in the southeastern part of the area is flat or gently undulating. North of Jackson there is a well-developed plain at an altitude of 230 to 250 feet above sea level. This plain was developed over the entire area, but north of Stave Creek and west of the Tombigbee it is so much dissected that the country is very rough and hilly. The hills are particularly rough and steep-sided in much of the area along Satilpa Creek, on the east side of the river, and between Santa Bogue and Turkey creeks, on the west side. (See explanation under description of Tallahatta buhrstone.) North and west of these areas the country is also hilly, but in general the slopes are more gentle, with here and there flat rolling lands and even small areas of prairie land.

A list of altitudes may be of value to oil companies or others who may do more detailed work in the area. The following precise altitudes were determined by the United States Corps of Engineers and refer to "mean low tide" of the Gulf of Mexico, being 1.256 feet lower than "average tide level" at Mobile, the datum on which the level line was originally run.

Bench marks on Tombigbee River, Ala., between Jackson and Pennington.

Location.	Designation.	Altitude (feet).	Description.
Bridge pier, Jackson, Ala.	U. S. B. M. Jackson Bridge.	43.262	Southern Railway bridge pier on right bank of Tombigbee River, Ala.; brass bolt cemented in granite coping 4 feet from upstream end of pier, 99¼ miles from Mobile.
Lock No. 1, St. Stephens, Ala.	U. S. B. M. Lock No. 1.	20.692	Upper end of bank wall, lock 1, Tombigbee River, Ala.; brass bolt cemented in concrete in upper corner of valve-stand recess, 111 miles from Mobile.
Lock No. 2, Pennington, Ala.	U. S. B. M. Lock No. 2.	33.964	Upper end of bank wall, lock 2, Tombigbee River, Ala.; brass bolt cemented in concrete coping 5 feet from upper end and 8 feet from face of wall, 182 miles from Mobile.

A close approximation to the altitude of any point along Tombigbee River may be obtained by subtracting 4.8 feet from the gage reading below lock No. 1, near St. Stephens, for points below that place and by adding 5.7 feet to the gage reading of the lower pool at lock No. 2 for the altitude of the water surface in the pool between locks Nos. 1 and 2.

GEOLOGY.

STRATIGRAPHY.

GENERAL SECTION.

The accompanying table gives a list of the formations into which the rocks of the area, both those exposed at the surface and those underlying it at a moderate depth, have been divided. The exposed rocks belong to the Hatchetigbee and overlying formations. The unexposed rocks, which crop out in the region to the north at a distance of 20 to 80 miles and dip under this area, belong to the Bashi and underlying formations. The range in thickness and the general lithologic character of these formations are also given in the accompanying table. For the exposed rocks these descriptions apply to their outcrop in this area; for the unexposed rocks, which will be encountered in deep drilling, the descriptions are based on their nearest outcrops to the north, where their character is assumed to be most comparable with that in the area.

The areal distribution of the exposed rocks, from the Hatchetigbee to the Vicksburg formations, is concentric in arrangement. (See Pl. XXVI.) The area of outcrop of the oldest exposed formation, the Hatchetigbee, is centrally located, and the formations overlying it are arranged in ascending order around it up to the Vicksburg group. The formations surrounding the Hatchetigbee formerly extended over it but have since been removed by erosion. The Catahoula sandstone crops out south and southwest of this area a short distance beyond the area mapped. The formations overlying the Catahoula sandstone are irregular in distribution and are spread over all the other formations in blanket fashion, completely hiding them over large areas. The unexposed formations are nearest the surface, where the oldest exposed formation, the Hatchetigbee, crops out.

Section of formations involved in the Hatchetigbee anticline, Ala.

System.	Series.	Group.	Formation.	Thickness in feet.	Lithologic character.
Quaternary.	Recent.		Alluvium.		Clay, silt, and sand along present streams.
	Pleistocene.		Alluvial terrace deposits.		Sand, gravel, and clay.
Tertiary.	Pliocene.		Citronelle formation.	0-100	Terrace sand and gravel.
	Oligocene.		Catahoula sandstone.	0-200	Light-gray sands, sandstones, and greenish-gray siliceous clays.
			"Coral limestone."	0-90	Limestone, hard and soft beds alternating, composed in part largely of corals.
		Vicksburg.	Marianna limestone.	0-90	Limestone, light gray to white, soft, chalky ("chimney rock") below, and hard, semicrystalline, cavernous (Glendon limestone member, locally termed "horsebone") above.
			Red Bluff clay.	20-40	Glauconitic clay, marl, and marly limestone below and plastic greenish-gray clay and gypsiferous and in places carbonaceous clay above.
	Eocene.		Jackson formation.	80-115	Clay, sand, and indurated marl; plastic bluish-green clay at base, followed above by medium fine-grained sand, light-gray indurated marl, and plastic gray or greenish-gray clay at top.
		Claiborne.	Gosport sand.	40-200	Greensand and indurated glauconitic sandy marl and subordinate beds of glauconitic clay; replete with shells, especially the greensand.
			Lisbon formation.		Sand, clay, indurated marl, sandstones, and oyster beds; the sands are highly glauconitic and weather red. Almost entirely marine; in large part highly fossiliferous.
			Tallahatta buhrstone.	20-200	Claystone, sandstone, and argillaceous sandstone, light gray, greenish gray, or green, glauconitic, medium to thin bedded, noncalcareous, highly siliceous, sparingly fossiliferous except in few beds.
		Wilcox.	Hatchetigbee formation.	200-300	Sand, laminated sand and clay, sandy clay, and plastic clay; these materials are light to dark gray or greenish gray when fresh, but weather to yellow or brown. A large part of the formation is lignitic, but it also contains numerous beds of marine shells.
			Bashi formation.	80-125	Greensand marl, sandy clay, and beds of lignite; in upper part this formation contains marine shells in abundance and in lower part numerous thin beds of lignite.
			Tuscahoma formation.	140-200	Sandy clays, sands, and greensands, gray in color and containing several shell beds.
			Nanafalia formation.	200-250	Clays and sandy clays, indurated and in part glauconitic, followed below by light-gray sands, greensands, and sandy clays; lignite is present at base of formation in some places, and marine shells are abundant in upper part.

Section of formations involved in the Hatchetigbee anticline, Ala.—Continued.

System.	Series.	Group.	Formation.	Thickness in feet.	Lithologic character.
Tertiary.	Eocene.	Midway.	Naheola formation.	150-200	Clay and sand beds, alternating; sands are gray and glauconitic and clays are dark gray to black and sandy; marine shells in lower part.
			Sucarnochee clay.	100-200	Clay, dark brown to black, hard and dense; shells abundant at some places and absent at others.
			Clayton limestone.	0-25	Limestone, chalky limestone, and hard limestone beds, white to light gray in color, in part clayey and in part sandy. This limestone is absent in some parts of southwestern Alabama.
Cretaceous.	Upper Cretaceous.		Ripley formation.	0-150	Sands, clays, marls, and impure limestones; absent in part of southwestern Alabama, where it merges into Selma chalk; entirely of marine origin.
			Selma chalk.	900-1,000	Chalk, chalky limestone, and thin beds of pure hard limestone; the chalk is grayish white or bluish gray to dark gray, in part clayey and in part sandy.
			Eutaw formation.	400-500	Sands, laminated sand and clay, and thin beds of lignitic clays; sands are marine, in part massive and in part cross-bedded.
			Tuscaloosa formation.	300-1,000	Sands, clays, and gravels, irregularly bedded, nonmarine; contain carbonaceous and lignitic beds in upper part and gravel in the basal part; sands and clays are gray to dark gray or green.

FORMATIONS EXPOSED.

WILCOX GROUP.

HATCHETIGBEE FORMATION.

The Hatchetigbee formation, the youngest unit of the Wilcox group, consists mainly of soft lignitic sands; clays, in part laminated; and marls and sandy clays containing numerous shells. The marine beds are either confined to the upper part of the formation or are most conspicuous there. The formation as a whole has a gray or brownish color when fresh, but on weathering it becomes gray or yellow, and stands in sharp color contrast with the upper Claiborne formations (Lisbon and Gosport), which it most closely resembles lithologically. In its lower part hard dark-gray glauconitic sandy concretions of fantastic shapes are present. The formation was named from Hatchetigbee Bluff, on Tombigbee River, near Frankville. Only its upper part, about 80 feet, is exposed there; and it is overlain by typical claystone of the Tallahatta, and its lower part is concealed below water level in the river. This exposure shows soft sands, clays, and marls, in large measure lignitic, though it contains two prominent beds of marine shells. As the basal beds of the formation are not exposed in this area its total thickness here is unknown.

The maximum exposed thickness at this place is probably 150 feet, whereas its total thickness farther north is estimated by Smith to be 175 feet.

The Hatchetigbee weathers readily into plastic clay and sandy clay; fresh exposures are rare. The formation contains no easily recognizable beds, and detailed structural studies are difficult within the area of its outcrop because of the lack of distinctive beds and because the bedding is uneven and measurements of local dips are difficult to obtain and of little value.

A conspicuous bed of clay pebbles and boulders is exposed 1 mile northwest of Bladon Springs, on the road to Barrytown, near or at the top of the Hatchetigbee. Small clay pebbles are present in the lower part of a 6-foot bed of glauconitic sand, and within 10 to 15 feet to the southeast the layer of pebbles thickens from a fraction of a foot to 2 feet and the pebbles become larger. Still farther along the bedding the clay pebbles and boulders compose almost the entire bed, but the clay is broken into irregular-shaped masses of different sizes and has a worm-eaten appearance. The "worm holes" are about half an inch in diameter and are filled with fine glauconitic sand, the matrix of the pebbles. Similar conditions are seen for 100 feet to the south and for a quarter of a mile to the northeast. It is significant that these clay pebbles and boulders occur at or near the contact of the Hatchetigbee with the Tallahatta buhrstone and, although there is no convincing evidence of an unconformity between them, shallow water with shifting currents must have prevailed here near the end of Hatchetigbee time.

The outcrops of the Hatchetigbee are confined to two areas. (See Pl. XXVI.) One extends from a point a short distance south of Jackson Creek northwestward almost to Silas; this area of outcrop lies along the crest of the Hatchetigbee anticline. The other area extends from a point near Bassett Creek, 3 miles southeast of Jackson, southward nearly to Oven Bluff, on Tombigbee River; this area lies along the east side of the Jackson fault. Were it not for this fold and fault, the Hatchetigbee formation would be normally from 400 to 500 feet below the surface.

CLAIBORNE GROUP.

TALLAHATTA BUHRSTONE.

The Tallahatta buhrstone immediately overlies the Hatchetigbee formation and when unweathered is in sharp lithologic contrast with the Hatchetigbee as well as with the upper Claiborne formations (Lisbon and Gosport) above. It consists of a fairly uniform series of claystones, glauconitic sandstones, and subordinate beds of clay and sand. Its most conspicuous features are its color and induration.

The unweathered Tallahatta is light gray, greenish gray, or rarely, where the beds are highly glauconitic, bright green; it weathers to form deep-red or orange-colored clay and sandy clay, which are practically indistinguishable from the weathered clays of the Lisbon above. The formation is separated from those overlying and underlying it on the basis of its lithology, particularly its degree of induration, which is much greater than that of the beds above and below it, causing its beds to stand up prominently.

In detail, this formation consists of medium to thin bedded light-gray, greenish-gray, or green indurated clay or claystone alternating with medium to coarse grained glauconitic, in part highly argillaceous sandstone and indurated sandy clays. It is in general highly siliceous, noncalcareous, and without conspicuous carbonaceous beds. The claystones are in the main hard, dense, micaceous, and greenish gray when fresh; they ring when struck with a hammer and break with a conchoidal fracture. On weathering they become softer and gray or light gray and finally form red plastic clay. Fresh beds of claystone commonly show at right angles to the bedding two sets of conspicuous joints which cause them to break up into irregular rectangular fragments. There are all gradations from claystones to sandstones of coarse grain. Many of the sandstones are highly glauconitic, clayey, and exceptionally fossiliferous. In many of the rocks sand and clay are irregularly distributed; thus there are small masses of pure sand and masses of pure clay in the same rock. Clay galls, or indurated pebbles of clay, are common in the sandstones. On weathering the slabby layers of sandstone, particularly in the upper part of the formation, develop on their under sides irregularly branching tubular markings that are probably of concretionary origin, although some of them have the appearance of organic remains.

An interesting feature of this formation is the amount of silification that it has undergone. This is seen not only in the induration of the original clays and sands to claystones and sandstones but also in the formation of veins of laminated agate and quartzitic dikes. The laminated agate is abundant on the Jackson-Coffeeville road near J. A. Bolen's house and on the old Bladon Springs-Cullomburg road about halfway between those towns. Dikes of quartzite were found on Souwilpa Creek at White Bluff, a few miles below Silas, where they trend due north and dip about 85° E. The material on the two sides of the dikes is essentially the same, and along the strike the quartzite of the dikes grades into the country rock. It is evident that the dikelike bodies of quartzite were formed from the silification of the material inclosed between two parallel joints. To judge from the piles of scraps of this material near by and the number of arrow heads made of it, the Indians used it extensively. Similar dikes were seen in a deep branch flowing into Bassett Creek from the south about

3 miles southeast of Jackson. Here the dikes are almost vertical and trend N. 70°–80° E.

North and northwest of Jackson the outcrops of the Tallahatta entirely surround those of the Hatchetigbee and extend from a point south of Jackson Creek northwestward almost to Silas; a small disconnected area of the Tallahatta is found near the head of Stave Creek, and a narrow belt of it extends from a point 2 miles east of Jackson southward to the Lower Salt Works. (See Pl. XXVI.) Owing to the superior hardness of this formation, the area of its outcrop is exceptionally rough and hilly, particularly between Santa Bogue and Turkey creeks, west of Tombigbee River, and along Jackson Creek on the south.

Smith gives 300 feet as the minimum thickness of this formation, an estimate which the writer considers too large for this area. No locality was found where the total thickness of the Tallahatta could be directly measured, but from the width of its outcrop and its rate of dip it is believed to have a maximum thickness of not more than 200 feet in the northern part of this area and about 20 feet in the southern part, near the Lower Salt Works. Although this formation would be expected to thin to the south, away from the source of the sediments, the marked amount of thinning may be in part due to the absence of induration in the lower beds, which causes them to be grouped with the underlying formation, the Hatchetigbee.

The Tallahatta conformably overlies the Hatchetigbee, and there is generally a gradual transition from one to the other, as shown in the Hatchetigbee Bluff, although shallow-water conditions with shifting currents prevailed at some places during the transition epoch. (See p. 289.) The relation of the Tallahatta to the overlying Lisbon is not clearly revealed, and at one place, at least, there is evidence of an unconformity between them or of marked irregularities in deposition, which have not been observed within the Tallahatta. In the south bluff of Souwilpa Creek, in the SW. ¼ NW. ¼ sec. 32, T. 10 N., R. 3 W., 2 miles northeast of Silas, is a well-exposed section of the top of the Tallahatta and the base of the Lisbon. The beds of claystones and sandstone in the lower part of the bluff are cut by at least three faults(?), which cause the beds on the two sides to dip in opposite directions at different angles. These faults(?) and associated joints do not appear to traverse a hard massive bed above, which overlies horizontally beds that appear to dip as much as 18°. The differences in the dip of the beds near the base of the bluff afford the most conspicuous evidence of faults of considerable magnitude, but these differences may be explained as extreme cases of cross-bedding, although numerous joints and one or two small faults are clearly recognizable.

LISBON FORMATION AND GOSPORT SAND.

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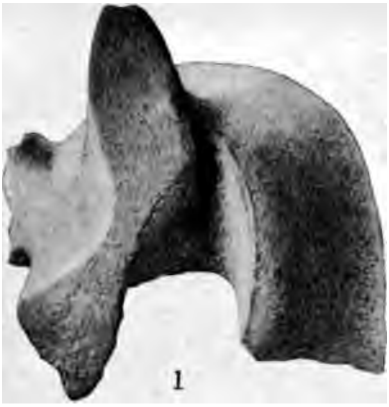
The Lisbon formation in the northwestern part of the area consists of glauconitic sand and clay, with prominent beds of oysters in its upper part and scattered beds of light-gray indurated marl, calcareous sandstone, gray to yellow micaceous spongy clay, and medium to coarse grained glauconitic sands replete with shells. In a few localities the upper beds are carbonaceous and contain scattered crystals of gypsum. The beds of *Ostrea sellaeformis*, the highly glauconitic character, and the deep-red color on the weathered surfaces are the chief characteristics of the formation. *Ostrea sellaeformis*, shown on Plate XXVII, is the common diagnostic fossil by which the formation may be recognized and traced from place to place. The general character of the Lisbon in the northwestern part of the area is shown in the following section:

Partial section of Lisbon formation and overlying sand 4 miles west of Gilbertown, near center of sec. 25, T. 11 N., R. 4 W.

	Feet.
Top of hill.	
Terrace sand (probably Citronelle): Sand, bright yellow to red, argillaceous	60
Lisbon formation:	
Sand and clay laminated, gray to brown, in part carbonaceous, weathering red	15
Clay, spongy, grayish yellow, sandy	12
Sand, highly glauconitic	6
Marl, more or less indurated, gray, glauconitic; oysters and pectens abundant in certain layers	10
Sand, calcareous; oysters abundant	2
Sand, indurated, calcareous, packed with *Ostrea sellaeformis* and other fossils	2
	107

At a number of places in the northwestern part of the area beds of carbonaceous clay and sand are present in the upper part of the formation, above some of the prominent beds of oysters, as in the foregoing section.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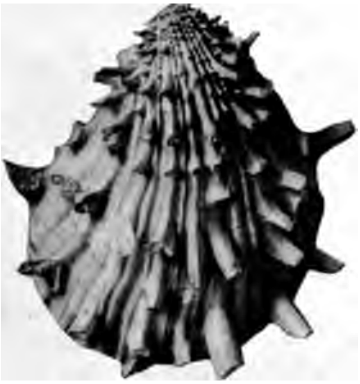
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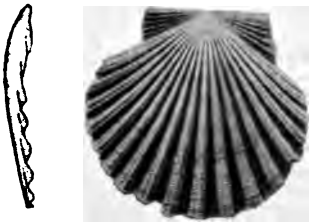
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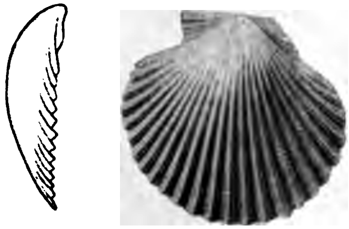
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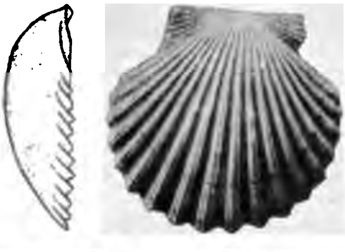
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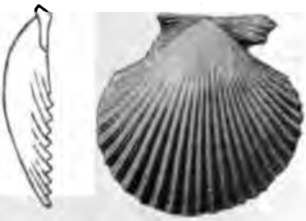
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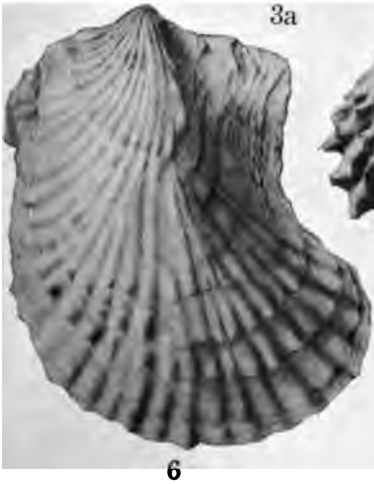
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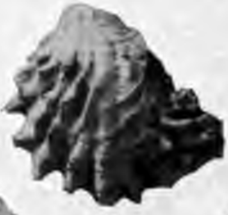
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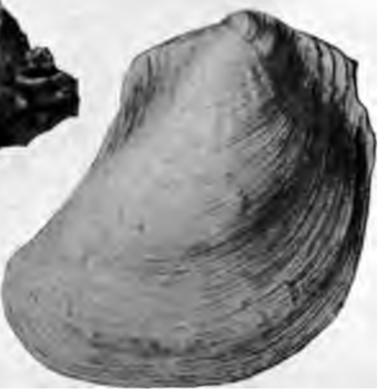
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CHARACTERISTIC FOSSILS OF THE JACKSON FORMATION AND CLAIBORNE AND VICKSBURG GROUPS.

alabamensis Morton; 2, *Ostrea vicksburgensis* Conrad; 3, 3a, *Pecten poulsoni* Morton; 4, 4a, *Pecten perplanus* Morton; 5, *Spondylus dumosus* Morton; 6, 6a, *Ostrea sellaeformis* Conrad.

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Partial section of Lisbon formation and overlying sand 4 miles west of Gilbertown, near center of sec. 33, T. 11 N., R. 4 W.

	Feet.
Top of hill.	
Terrace sand (probably Citronelle): Sand, bright yellow to red, argillaceous	60
Lisbon formation:	
Sand and clay laminated, gray to brown, in part carbonaceous, weathering red	15
Clay, spongy, grayish yellow, sandy	12
Sand, highly glauconitic	6
Marl, more or less indurated, gray, glauconitic; oysters and pectens abundant in certain layers	10
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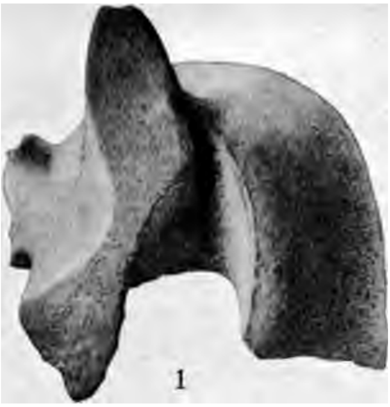

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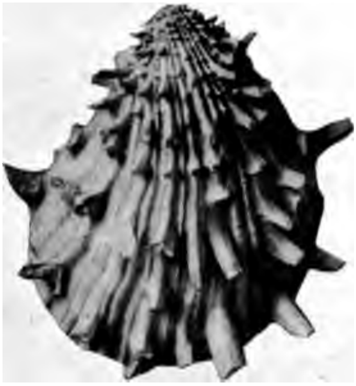

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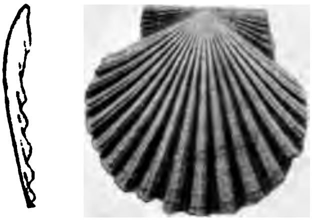

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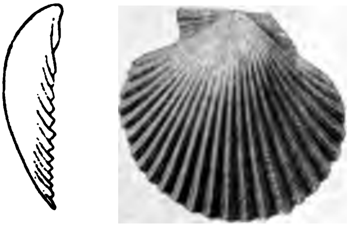

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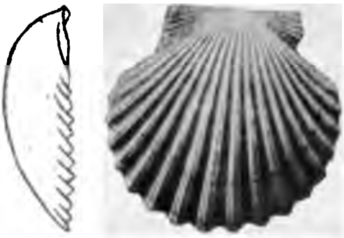

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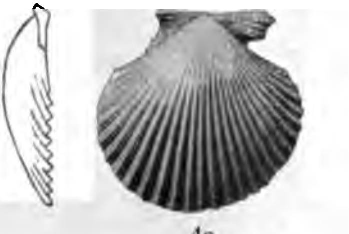

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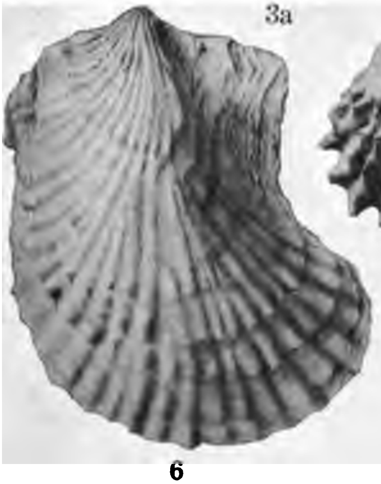

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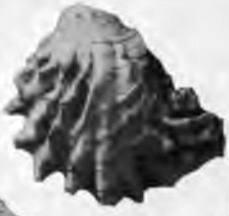

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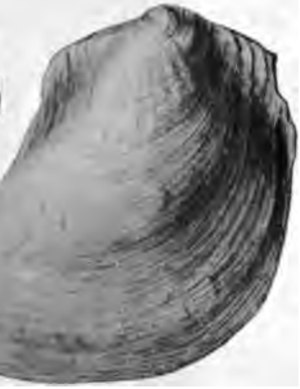

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	Feet.
Top of hill.	
Terrace sand (probably Citronelle): Sand, bright yellow to red, argillaceous	60
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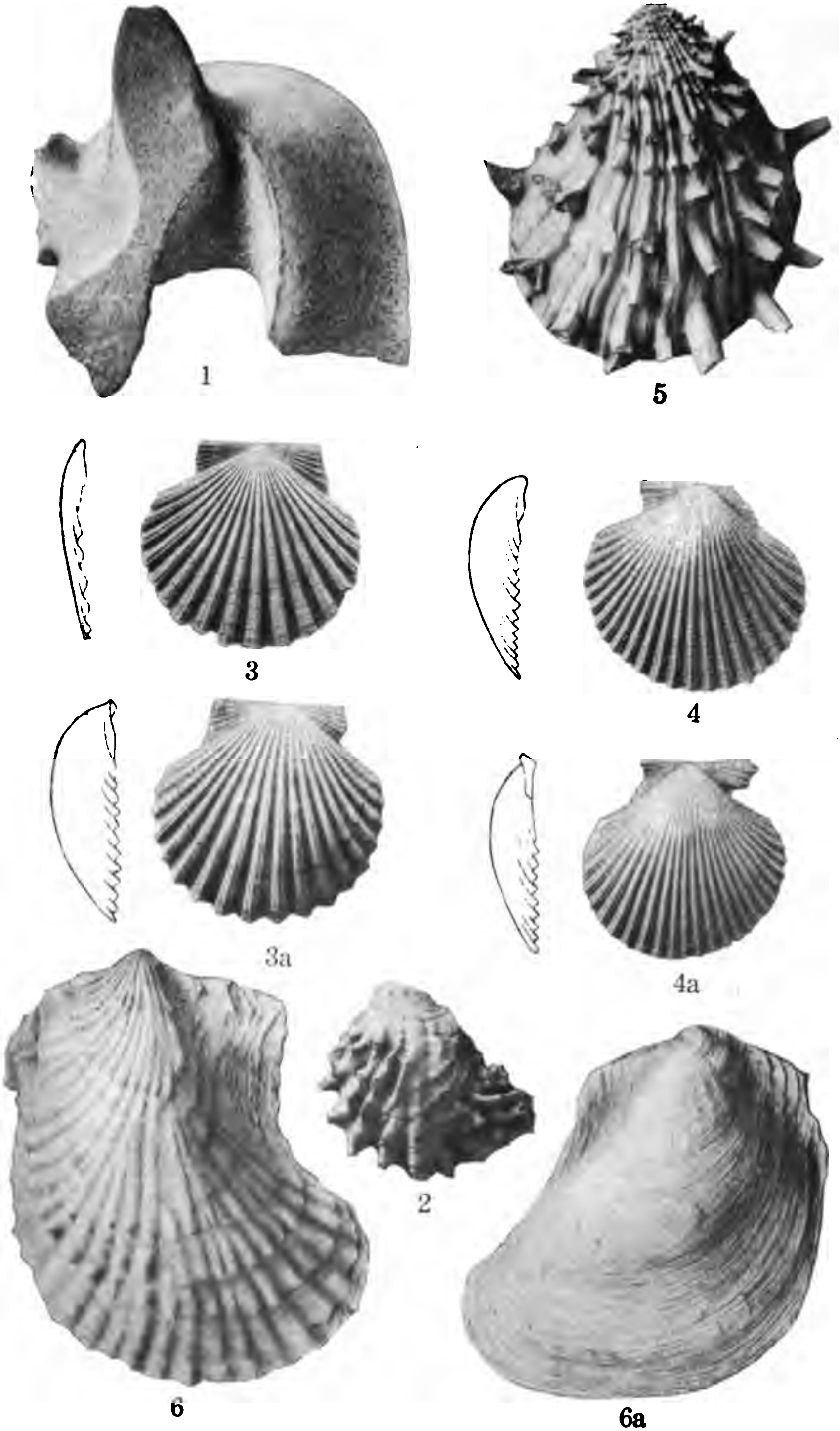

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The Lisbon, which is typically developed in the northwestern part of the area, thins conspicuously toward the southeast; it maintains its lithologic characteristics to a point a short distance south of Bassetts Creek, near Jackson, but beyond that it is not separable, on the basis of the present work, from the overlying Gosport, both formations having become much thinner and more calcareous. The following composite section shows the greater part of the Lisbon and Gosport formations in the extreme southeastern part of the area:

Partial section of Hatchetigbee, Tallahatta, Lisbon, and Gosport (?) formations at Lower Salt Works, near Oven Bluff, Clarke County, Ala.

Section measured on hill slope above Lower Salt Works.

Top of hill.	
Gosport (?) and Lisbon formations:	Feet.
Marl, sandy, highly calcareous	8
Clay marl, sandy, gray to yellow	5
Limestone, hard, impure; casts of shells abundant	1
Marl, sandy, in part indurated	7
Sand, highly glauconitic, much weathered	7
Sandstone, hard, calcareous	1
Marl, gray, indurated, glauconitic; contains pectens and *Orbitoides*	4
Tallahatta buhrstone: Claystone or indurated clay, typical of Tallahatta	15–20

Section measured on old road one-fourth mile north-northeast of Lower Salt Works.

Hatchetigbee formation: Sand and clay, lignitic	45
Limestone Creek flat.	

The conspicuous beds of oysters found farther north are absent here. Plastic clay, which looks like the weathered clay member of the lower Jackson, is poorly exposed a short distance above the top of this section.

The Gosport sand consists of 10 to 15 feet of medium to fairly coarse-grained, highly glauconitic sand with subordinate layers of clay below and from a few feet to 10 or 15 feet of light-gray indurated glauconitic sandy marl and marly limestone above. This sandy marl may properly belong to the Jackson formation. The glauconitic sand is characteristic of the beds from the northwestern part of the area southeast as far as Jackson, but farther south it is not definitely recognized. The indurated marl has a thickness of only 1 or 2 feet in the northwestern part of the area but increases to a maximum of 12 to 15 feet near Jackson to the southeast. This marl, because of its lithology, its position between greensand below and greenish-gray plastic clay above, and its peculiar fossils, is a valuable key bed which can be easily traced over the entire area. The Gosport sand is characterized by a profusion of fossil shells among which may be mentioned *Periarchus lyelli.* (See Pl. XXVIII.)

Fresh exposures of the indurated marl are found on Willow Branch, 3 miles southwest of Silas;[1] on the main branch of the Choctaw Lumber Co.'s railroad 4 miles west of Silas, three-fourths of a mile west of Elias Creek; on the road between Pevey's Landing and Bigbee, 2½ miles north-northeast of Jackson, near the NE. ¼ SW. ¼ SW. ¼ sec. 28, T. 7 N., R. 2 E.; and at many other places.

One of the most southerly sections that shows typical Gosport sand is given below:

Partial section of Jackson and Gosport formations, 3 miles southeast of Jackson, near J. J. Chestine's house, in the center of the SE. ¼ NW. ¼ sec. 14, T. 6 N., R. 2 E.

	Feet.
Jackson formation:	
Clay, grayish yellow.	
Sand, indurated, calcareous, clayey below	6
Clay, bluish green, micaceous, sandy, containing shells and becoming plastic below	30
Clay, bluish green, plastic, calcareous	15
Gosport sand:	
Limestone, hard[2]	2
Marl or marly limestone, gray, indurated	13
Sand, green, highly glauconitic; fairly coarse grained; *Periarchus lyelli* very abundant	8
Sand, green, glauconitic, argillaceous, fine grained	4
Base of small waterfalls.	
	78

In the hills near by thin layers of *Ostrea sellaeformis* were found in the beds below the base of this section and above typical exposures of Tallahatta.

The following section shows the character of the beds at the horizon of the Gosport sand farther south, where they have lost their distinctive character.

Section in east bank of small branch 2 miles southwest of Rockville, in the NW. ¼ NW. ¼ sec. 14, T. 5 N., R. 2 E.

	Feet.
Jackson formation: Clay, bluish green, plastic.	
Gosport and Lisbon (?) formations:[3]	
Marl, indurated, sandy	5
Sandstone, hard, calcareous	1
Marl, hard, sandy	12
Clay, greenish gray, fine grained, plastic	5½
Marl, hard, sandy, or marly limestone; casts of shells	3
Marl, sandy, bluish green when fresh, weathering yellow, followed below by hard marl and highly glauconitic sand with shells in creek bed below	5
	31½

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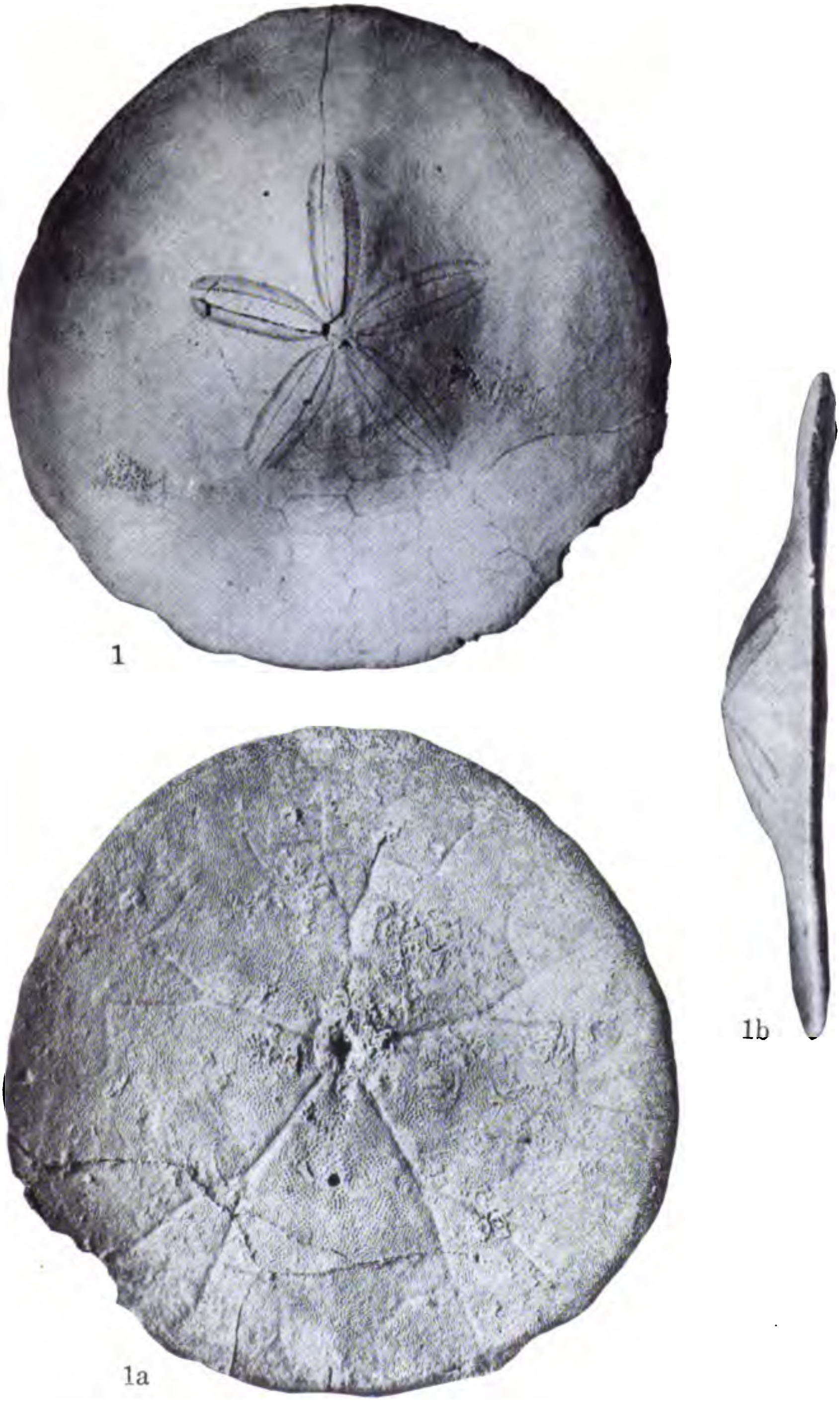
[1] See section on Willow Branch, p. 297, also section given by C. W. Cooke (The age of the Ocala limestone: U. S. Geol. Survey Prof. Paper 95, p. 115, 1915).

[2] This limestone and the underlying marl may properly belong to the Jackson formation.

[3] The upper part of this section may be properly referred to the Jackson formation.



PERIARCHUS LYELLI (CONRAD), A CHARACTERISTIC FOSSIL OF THE UPPER CLAIBORNE.

The Lisbon and Gosport formations practically encircle the Hatchetigbee uplift (see Pl. XXVI); at its northwest end they form a broad belt that extends from a point near Silas almost to the Mississippi State line; and on the southeast they continue on the east side of the Jackson fault to the Lower Salt Works but with much diminished thickness. The thickness of these formations decreases from a maximum of probably 200 feet near Silas to about 125 or 150 feet near Pevey's Landing, on Tombigbee River; about 80 or 100 feet 3 miles southeast of Jackson; and about 40 to 50 feet at the Lower Salt Works. Dr. Smith[1] has suggested that this pronounced thinning of the Tallahatta and higher Claiborne formations is due to the uplifting of the southern part of this area during part of the time that beds were being deposited elsewhere in the area. The writer believes that this was not the case, but that all the formations are present in the southern part of the area with diminished thickness.

No unconformities have been recognized either at the top or at the base of the Lisbon and Gosport. The transition between these formations is gradual and complete. A marked change in the lithology appears at the base of the Lisbon, where it rests on the noncalcareous indurated claystones and sandstones of the Tallahatta. Likewise, there is a sharp change in the lithology from the indurated marl at the top of the Gosport to the plastic greenish-gray clay of the lower Jackson.

JACKSON FORMATION.

The name "St. Stephens limestone" was formerly applied to the dominantly calcareous marine deposits of Alabama, which immediately overlie the Claiborne group, and were considered the equivalent of the Jackson and Vicksburg formations of Mississippi. Vaughan[2] and, later, Cooke[3] suggested that these Mississippi formations could be recognized in Alabama; and Cooke,[4] as the result of his faunal and stratigraphic studies, has definitely recognized those formations in this area. In western Alabama the name Jackson formation is applied to the lower 100 to 125 feet of the "St. Stephens," which has a total thickness of 325 to 350 feet, and the name Vicksburg group to the overlying 100 to 130 feet. The upper 80 to 90 feet is represented by the "Coral limestone" at Salt Mountain. The original name, "St. Stephens limestone," has therefore been abandoned.

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[1] Smith, E. A., informal communication.

[2] Vaughan, T. W., in Willis, Bailey, Index to the stratigraphy of North America: U. S. Geol. Survey Prof. Paper 71, pp. 738, 739, 1912.

[3] Cooke, C. W., The age of the Ocala limestone: U. S. Geol. Survey Prof. Paper 95, pp. 108 (footnote), 115, 1915.

[4] Cooke, C. W., unpublished notes.

The Jackson, as here recognized, consists of four well-defined and easily recognized lithologic units, as follows:

Subdivisions of Jackson formation.

	Feet.
4. Clay, light greenish gray, calcareous, plastic, with small white chalky limestone concretions	8–20
3. "*Zeuglodon* bed": Marl, light gray, indurated, sandy, glauconitic, weathering yellow, characterized by large *Zeuglodon* bones, *Aturia alabamensis* (commonly called "knees"), *Pecten perplanus*, echinoids, shark teeth, and fish vertebrae	8–15
2. Sand, medium fine grained, calcareous, in part argillaceous, grading into clay below, greenish gray when fresh and weathering grayish yellow to brownish yellow	20–30
1. Clay, bluish green or greenish gray, plastic, lumpy, calcareous, in part micaceous and sandy; weathers olive-green or grayish yellow and finally to black sticky prairie soil; contains in places small chalky limestone concretions	30–50

The lower clay (No. 1 of the section) is massive and, in its upper part, micaceous and sandy, grading into the sand above; when wet and fresh it is exceedingly slippery. In appearance it resembles the clay at the top of the Jackson (No. 4 in above section), but the two clays may be distinguished by slight differences in lithology, by the difference in thickness, and particularly by the difference in the underlying and overlying beds. This clay has a maximum thickness of about 50 feet in the northwestern part of the area and thins toward the southeast to about 20 or 30 feet south of Jackson.

No. 2 of the section consists of micaceous, clayey sand. Its uniform medium-fine grain, its brownish rather than bright-yellow or orange color, and its calcareous nature make it readily distinguishable, even on weathered surfaces, from the more recent terrace sands.

The "*Zeuglodon* bed," No. 3 of the section, is easily recognized because of its uniform character over the area, its position above beds of sand and below beds of plastic greenish-gray clay, and the presence of the characteristic fossils *Aturia alabamensis*, *Pecten perplanus*, and *Zeuglodon* vertebrae. (See Pl. XXVII.) This marl has a fairly uniform thickness of 8 to 15 feet over the entire area. Being harder than the associated beds, it is fairly well exposed and serves well as a key rock. Its outcrop is marked at many places by a belt of cedars. It contains at a few places thin lenticular masses of bituminous material, which closely resembles inspissated petroleum.

The clay at the top of the Jackson (No. 4 of the section) is lithologically similar to that at the base, but is thinner and more sandy and limy. It is not known to contain any characteristic fossils, but its surface is commonly strewn with shells of *Ostrea vicksburgensis* (see Pl. XXVII), which weather out of the beds near the base of the Red Bluff clay above. The presence of these shells scattered over its surface, of the indurated marl below, and of the characteristic Red Bluff beds above makes this clay easily recognized over the entire area. It thins from about 20 feet in the northwestern part of the area to about 8 or 10 feet southeast of Jackson.

Although these lithologic divisions of the Jackson are partly exposed at many places in this area, there are few places where practically the entire section is as well exposed as on Willow Branch.

Section on Willow Branch 4 miles southwest of Silas, on road to Fail.[1]

Section measured on southwest side of branch.	
Hilltop.	Feet.
Citronelle formation: Sand, orange-colored, argillaceous in part; some beds of slabby ferruginous sandstone	60
Jackson formation:	
Clay, light greenish gray, highly calcareous, plastic, sandy and glauconitic in lower part, weathering red	20
Marl, light gray, indurated, sandy, glauconitic, containing hard ledges below and becoming clayey above	15
Sand, medium grained, argillaceous, weathering bright yellow to orange-colored and leaching gray	20
Sandy marl, grayish yellow, grading to plastic green clay below	10
Clay, light grayish green, plastic, with numerous small concretions of chalky limestone	48
Section measured on northeast side of branch.	
Gosport sand (possibly includes part of the Lisbon formation below):	
Marl, grayish yellow, indurated, glauconitic, sandy, forming prominent ledge[2]	1½
Marl, brownish yellow, weathered, glauconitic, sandy, containing casts of shells	7
Greensand marl, dark greenish gray	3½
Sand and clay, laminated, glauconitic in upper part	7
Sand, greenish black, replete with shells	2
Clay, dark, carbonaceous, hackly	5
Sand, weathered, argillaceous, glauconitic	1
Sand, medium grained, bright brownish yellow, weathered glauconitic	8
Bottom of Willow Branch a few feet below.	
	208

The outcrops of the Jackson formation completely encircle the Hatchetigbee uplift, like those of the Gosport, Lisbon, and Tallahatta, and extend from a point near Salt Creek, north of Jackson, northwestward into Mississippi. To the southeast the outcrop is considerably narrower than to the northwest, and at the southeast end of this uplift it is offset by the Jackson fault. (See p. 305.) On the east side of the fault the beds continue to the southeastern part of the area, whereas on the west side only one small area of outcrop is known, near Bassetts Creek, southeast of Jackson. In these areas underlain by the Jackson formation the exposures are fairly numerous along stream channels but are concealed at most places in the uplands. The best exposures are found (1) at Willow Branch (see section, p. 297); (2) along the road leading from Pevey's Landing to Bigbee; (3) in the bluffs at the road crossing of both branches of Ulkinask Creek, 3 to 4 miles north of Coffeeville; (4) on J. A. Bolen's place in sec. 31, T. 8 N., R. 2 E., 1½ miles northwest of McVey; and (5) 2½ miles north of Jackson. Other exposures are marked by a cross on Plate XXVI.

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[1] See also section by Cooke, C. W., op. cit., p. 115.

[2] This bed may properly belong to the Jackson formation.

The Jackson formation becomes more calcareous from the western part of the area eastward; near the Lower Salt Works, south of Jackson, the upper part of the formation is dominently calcareous, and still farther east, in Florida, the beds of Jackson age are named Ocala limestone.[1] The beds of Jackson age in the southeastern part of this area are intermediate in character between the typical Jackson of the section described above and the typical Ocala.

Within this area the Jackson rests conformably upon the Gosport sand and is overlain conformably by the Vicksburg group.

VICKSBURG GROUP.

SUBDIVISIONS.

The Vicksburg group in this area comprises 100 to 130 feet of what was formerly called the "St. Stephens limestone" and includes the following divisions:

Marianna limestone:
  Glendon limestone member.
  Soft chalky limestone called "chimney rock."
Red Bluff clay.

The whole of this group is dominantly calcareous with the exception of its basal formation, the Red Bluff clay. Its upper limit is not well marked, as it is in contact with alternating soft and hard layers of limestone, the "Coral limestone"; its base is equally indistinct, as it is underlain by similar marine deposits. Studied in detail, however, this group is easily separated in this area from the underlying Jackson, which composes the lower part of the "St. Stephens limestone."

RED BLUFF CLAY.

The Red Bluff clay, so named from its exposure in the bluffs of Chickasawhay River near Hiawannee, Miss.,[2] is the most variable formation of the Vicksburg group, both in thickness and in lithology. In general it consists in its lower part of 10 to 20 feet of glauconitic clay, marl, and marly limestone, with very abundant shells, particularly *Ostrea vicksburgensis* and *Spondylus dumosus* (see Pl. XXVII); in its upper part it consists of 20 to 30 feet of plastic greenish-gray clay, much like the lower clay of the Jackson when unweathered but highly gypsiferous and in places sandy; and dark carbonaceous clays in general not fossiliferous or only slightly so. This general succession of beds is shown in the following section:

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[1] Cooke, C. W., The age of the Ocala limestone: U. S. Geol. Survey Prof. Paper 95, pp. 107-117, 1915.

[2] Lowe, E. N., Mississippi: its geology, geography, soils, and mineral resources: Mississippi Geol. Survey Bull. 12, p. 86, 1915.

Section along road from Millry to Cullomburg, near the north line of sec. 9, T. 8 N., R. 3 W.[1]

	Feet.
Terrace sand to hilltops.	
Red Bluff clay:	
Clay, greenish gray, gypsiferous, with thin ferruginous beds; weathers yellow and red	30
Marl, light gray, indurated in layers; *Ostrea vicksburgensis* very abundant	10
Jackson formation:	
Clay, light gray to greenish gray, plastic	12
Marl, light gray, indurated; contains *Pecten perplanus*	12
Sand, medium fine grained, yellow, to foot of hill	10+
	74

In the south bluff of Ulkinask Creek, in the NW. ¼ sec. 33, T. 10 N., R. 1 W., is exposed a section almost identical with the one given above. At St. Stephens Bluff, on Tombigbee River, however, the formation is much thinner and consists largely of thin alternating beds of hard and soft marl and marly limestone. In this locality the entire formation is not exposed at one place, and its total thickness is not accurately known, although it is probably not more than 20 to 30 feet. (See section at St. Stephens Bluff, p. 300.) Farther southeast the formation becomes more calcareous and merges into the overlying "chimney rock;" at Oven Bluff, on Tombigbee River, the transition is complete.

The Red Bluff crops out along the northeast and southwest sides of the area, but because of its softness it weathers rapidly and is in general poorly exposed. It is easily distinguished from the Jackson, which it resembles lithologically, by its more ferruginous character, which causes it to weather yellow or red; by its content of gypsum; and by the presence of such fossils as *Ostrea vicksburgensis* and *Spondylus dumosus*. (See Pl. XXVII.)

MARIANNA LIMESTONE.

The Marianna limestone derives its name from Marianna, Fla., where it consists of soft, porous light-gray to white limestone, with subordinate beds of marl and chert.[2] This formation extends westward across Alabama into Mississippi, but in its western area the upper part of the formation contains beds of hard, cavernous limestone which have been named the Glendon limestone member.[1] The Marianna limestone of this area includes 55 to 75 feet of soft, porous light-gray to white chalky limestone, locally called the "chimney rock," overlain by 12 to 15 feet of hard, semicrystalline, rough, cavernous limestone (Glendon limestone member), locally termed "horsebone." These two divisions contain the most easily recognized beds of the area. The "chimney rock" has been widely quarried for building stone; when damp it is soft and easily cut with a saw, but on drying it hardens so as to make a fairly durable rock for chimneys and foundations.

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[1] This may be the locality where Cooke measured a section. (See Cooke, C. W., The age of the Ocala limestone: U. S. Geol. Survey Prof. Paper 95, p. 116, 1915.)

[2] Matson, G. C., and Clapp, F. G., A preliminary report on the geology of Florida; Florida Geol. Survey Second Ann. Rept., pp. 51-69, 1909. Matson, G. C., and Sanford, Samuel, Geology and underground waters of Florida: U. S. Geol. Survey Water-Supply Paper 319, pp. 73-79, 1913.

The upper part of the "chimney rock" and the Glendon member are well exposed at Glendon, a flag station on the Southern Railway east of Jackson, the type locality of the Glendon member. Here about 15 feet of Glendon limestone, of typical "horsebone" appearance, overlies an equal thickness of soft chalky limestone, composed in some beds of masses of *Orbitoides* (thin, round, flat shells from three-fourths to 1 inch or more in diameter). The most extensive exposures of the Marianna are found in St. Stephens Bluff and neighboring bluffs on Tombigbee River.

Partial section of Vicksburg group and Jackson formation at St. Stephens Bluff (Lovers Leap), Tombigbee River.

	Ft.	in.
Marianna limestone:		
Limestone, grayish yellow, hard, cavernous (Glendon limestone member or "horsebone")	13	6
Limestone, light gray to white, soft, porous, chalky, with *Pecten poulsoni*, *Clypeaster rogersi*, and *Orbitoides* ("chimney rock")	55	0
Concealed interval	15	6
Red Bluff clay:		
Marl and limestone, gray, hard and soft beds, glauconitic	6	4
Limestone, hard	1	0
Clay, greenish gray, glauconitic	9	8
Marl, light gray, indurated, glauconitic	1	0
Jackson formation:		
Clay, greenish grey; *Pecten perplanus* abundant	11	0
Marl, light gray, indurated, hard nodular layers; *Pecten perplanus* very abundant ("*Zeuglodon* bed")	10	0
Water level in Tombigbee River.		
	123	0

The "chimney rock" contains in the northeastern part of the area hard limestone ledges 1 foot or less thick at intervals of 6 to 8 feet throughout its thickness, as in a roadside exposure near the center of the NW. ¼ sec. 18, T. 8 N., R. 2 E., 1¼ miles north of Winn.

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[1] Cooke, C. W., manuscript awaiting publication by the Mississippi Geol. Survey.

The Marianna limestone crops out at intervals along the northeastern and eastern parts of the area from Oven Bluff, on Tombigbee River, to Womack Hill, and along the southwestern and western parts from Paynes to the Mississippi State line. (See Pl. XXVI.) The two divisions of this formation are so striking lithologically that they can be clearly recognized in this area without the aid of fossils; confusion arises only in its southeastern part, near Oven Bluff, where the Red Bluff and upper Jackson are similar in appearance to the "chimney rock." The most easily recognized characteristic fossils of the Marianna are *Pecten poulsoni*, *Clypeaster rogersi*, and *Orbitoides*.

"CORAL LIMESTONE."

The name "Coral limestone" was applied by Smith and Johnson [1] to the uppermost beds of what they termed the "White limestone" as exposed at Salt Mountain, Clarke County, including the Glendon limestone member, as described above, and the overlying limestone, a total of about 150 feet of strata. As the Glendon has been found to be of Marianna age and also to be unlike the beds above it, the term "Coral limestone" as tentatively used in this report is applied to the limestone beds overlying the Glendon.

At Salt Mountain the "Coral limestone" has a thickness of 80 to 90 feet and consists of alternating hard and soft beds of white limestone, part of which is composed largely of corals. The exposures there are not good and no detailed section was made of this formation. Salt Mountain is the only locality in this area at which so great a thickness of this formation is exposed.

CATAHOULA SANDSTONE.

The Catahoula sandstone is not exposed within the area mapped (Pl. XXVI), but for completeness it is briefly described, as it crops out a short distance beyond the southwestern limit of this area, beyond the outcrop of the Vicksburg group and the "Coral limestone."

This formation is well exposed in the vicinity of Healing Springs, Washington County, where it consists of gray to yellow sands, gray to bluish-gray clay, and indurated clay, and in the neighboring region, where it contains fine conglomerate, sandstone, and quartzite in addition. In this region, according to Matson,[2] the Catahoula has a thickness of probably less than 200 feet. It is nonmarine and unfossiliferous, except for a few fresh-water shells and plant remains, and is easily separable from the marine beds of the Vicksburg group below.

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[1] Smith, E. A., and Johnson, L. C., Tertiary and Cretaceous strata of the Tuscaloosa, Tombigbee, and Alabama rivers: U. S. Geol. Survey Bull. 43, pp. 18-20, 1887.

[2] Matson, G. C., The Catahoula sandstone: U. S. Geol. Survey Prof. Paper 98, p. 220, 1916.

PLIOCENE (CITRONELLE FORMATION) AND PLEISTOCENE SANDS AND GRAVELS.

After the deposition of the Catahoula sandstone there was a period during which no sediments were laid down in this region, and those that had been formed were uplifted, gently folded, and extensively eroded. Upon the eroded surface thus produced, which was relatively much lower than the present surface, terrace sands and gravels were deposited, covering in large measure the older formations of the area. In general the uplands are covered with this terrace formation, and only in the stream bottoms and along their bluffs, where active erosion has been taking place, are the underlying formations exposed. South of the latitude of Jackson the sands and gravels cover progressively more of the area until they pass below still more recent deposits, whereas to the north they cover progressively smaller areas until only small remnants are left and finally disappear entirely.

These deposits were formerly named "Orange sand" and later "Lafayette." Recently the name Citronelle formation[1] has been applied to those terrace deposits of Pliocene age which range in altitude in this area from about 230 to 450 feet. The Citronelle formation includes most but not all of the terrace sands of the area. The highest terrace deposit in this area reaches an altitude of 440 feet and is represented by a few scattered remnants of sand, gravel, and ferruginous sandstone capping high hills. The most extensive terrace deposit has an altitude ranging from 230 feet near Jackson to 280 or 290 feet near the Mississippi State line. A still lower but conspicuous terrace deposit occurs at about 170 to 180 feet.

The materials that constitute these terrace deposits are very similar, consisting of coarse sand and gravel below and fine sand, sandy clay, or loam above. In general the sands are bright red or orange colored and in many places where they are much weathered are with difficulty distinguished from the sands of the Claiborne group. The deposits of sand and gravel are more extensively developed near Jackson than elsewhere in the area.

ALLUVIUM.

The valley of the Tombigbee and its major tributaries is broad and flat, and much of the lowland along the river and within 5 miles of it is between 30 and 60 or 80 feet above sea level. The streams that meander through these lowlands are sluggish and during periods of overflow deposit a large percentage of the silt which they have carried down from their upper courses, where the gradient is higher. The bearing of such conditions on the study of the underlying rocks is evident: Exposures are to be looked for in the bottoms of the small streams near their heads, or along the bluffs of the larger streams either where smaller streams have cut through the bluffs or where the main streams themselves in meandering flow against them.

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[1] Matson, G. C., The Pliocene Citronelle formation of the Gulf Coastal Plain: U. S. Geol. Survey Prof. Paper 98, pp. 168-169, 1916.

STRUCTURE.

GENERAL FEATURES.

The formations of the Coastal Plain of southern Alabama dip normally to the south or southwest at a gentle rate and pass progressively beneath younger formations toward the coast. This simple structure is interrupted in the area near Silas, Bladon Springs, and Jackson by an uplift and fault—the Hatchetigbee anticline and Jackson fault—which disturb the normal dip and succession of the rocks and bring to the surface formations elsewhere deeply buried. The Hatchetigbee anticline exposes the Hatchetigbee formation, which would be normally about 400 to 500 feet below the surface and causes the dip on its northeast side to be reversed in direction and on its southwest side to be increased in amount. Had this upward fold not been worn down by long-continued erosion it would appear on the surface as a relatively high but well-rounded ridge, extending from a point 3 miles north of Jackson northwest past Bladon Springs and Silas into Mississippi. The crest of this ridge would be in the position marked on the accompanying map (Pl. XXVI) "Crest of the Hatchetigbee anticline." Erosion has reduced this upfold or anticlinal ridge to the level of the surrounding country and has exposed the underlying strata down to the Hatchetigbee formation, which represents the center of the uplift.

The uplift is continued beyond the southeast end of the Hatchetigbee anticline by the Jackson fault, which brings to the surface along its east side the same formation that crops out along the crest of the anticline. Other folds and faults that are subordinate to the major anticline and fault have been recognized but they have not been outlined in detail.

HATCHETIGBEE ANTICLINE.

The Hatchetigbee anticline is a broad, gentle rock fold, approximately 50 miles long and 20 miles broad, which extends from a point 2 miles north of Jackson in a N. 55° W. direction past Salitpa, Bladon Springs, and Silas into Mississippi. (See Pl. XXVI.) The center of the uplift is outlined by the outcrop of the Hatchetigbee formation, the oldest exposed formation in the area; the approximate axis of the anticline is shown on the accompanying map. The general shape and size of the anticline are indicated by the outcrops of the Tallahatta, Lisbon, Gosport, Jackson, and Vicksburg formations, which encircle the outcrop of the Hatchetigbee formation and formerly arched over it. (See cross section B–B′ on Pl. XXVI.)

The anticline is asymmetric; it has steeper dips on its southwestern side than on its northeastern. Its southeast end is abrupt, owing to the presence of the Jackson fault and probably of an unmapped fault at right angles to the fold. The axis of the fold is highest from a point a short distance north of Jackson Creek to Turkey Creek, 4 miles east of Silas, beyond which it pitches very gently to the north and northwest. There are two areas along this axis which are slightly higher than its general level—one near Salitpa and the other near Bladon Springs. The height of the axis of the fold is best determined from the altitude of the base of the Tallahatta formation, wherever that can be ascertained. South of Jackson Creek its base along the axis of the fold is about 150 feet above sea level. In the area near Salitpa the hills reach an altitude of 180 feet but are not high enough to reach the Tallahatta; in the hills east and northeast of Salitpa the base is at 150 to 180 feet and the dip there is to the northeast. It is quite certain, therefore, that the base near Salitpa would be more than 200 feet above sea level and probably as much as 250 feet. In the Hatchetigbee Hills, 1 mile northwest of Hatchetigbee Lake, the base of the Tallahatta reaches a maximum of not more than 160 feet above sea level. This area along the axis from sec. 22 to sec. 8 (sec. 7 in normal township), T. 8 N., R. 1 W., represents a slight "saddle" in the anticlinal axis. Farther northwest, along the axis, the base of the Tallahatta increases in altitude; in sec. 34, T. 9 N., R. 2 W., it is at about 190 to 200 feet. Near Bladon Springs the hills, which stand 180 to 190 feet above sea level, do not reach the Tallahatta, and in the hills southeast of Bladon Springs the base of the Tallahatta is at an altitude of 225 feet in its highest parts, where it is dipping strongly to the south. The altitude of the base along the axis near Bladon Springs would be more than 225 feet and might be as much as 275 or 300 feet above sea level. Farther northwest along the axis, in sec. 13, T. 9 N., R. 3 W., the base is at 200 to 210 feet, and thence it slopes gently northwestward to 140 feet in sec. 10 of the same township and is at about that level, or slightly higher, in the NE. ¼ sec. 31, T. 10 N., R. 3 W. Beyond that its altitude can not be determined except near Souwilpa, where it is about 100 feet, and in sec. 4, T. 10 N., R. 3 W., where it is about 70 feet above sea level.

Four miles east of Bolinger the axis of the uplift appears to branch; the main axis continues in its normal direction to the northwest and the secondary axis trends northwest and north, causing the Tallahatta buhrstone to be exposed in Souwilpa Creek 1 mile southwest of Barrytown and in Mill Creek 2 miles southeast of Gilbertown. The main axis appears to bend more to the west where it crosses the State line into Mississippi.

According to Cooke[1] the Vicksburg group has an abnormally wide outcrop along Chickasawhay River between Hiwannee and Waynesboro, a condition which suggests that there is in that area, which lies south of the normal continuation of the Hatchetigbee anticline, a lower but parallel fold, or possibly a structural terrace.

The axis of the Hatchetigbee anticline is not accurately determinable, as the anticline is broad and comparatively flat-topped and shows no well-defined axis. The dips on the flank of the anticline reach a maximum of 1° or 2° at a distance of 2 to 4 miles from the approximate axis. The beds on the southwest side of the fold probably continue to dip to the south at a variable angle beyond the limits of this fold all the way to the Gulf, probably without any pronounced folding; on the northeast side the beds dip from a fraction of a degree to 1° to the north, within 10 to 12 miles become approximately horizontal, and farther north gradually assume the normal southerly dip.

JACKSON FAULT.

The Jackson fault extends from a point near Stave Creek, 3 miles north of Jackson, southeast to Bassett Creek, south to Central Salt Works, and southwest to Tombigbee River near Oven Bluff. (See Pl. XXVI.) Its throw ranges from about 300 feet near its north end to at least 450 feet near its south end. The upthrow is on its east side, and near its central and southern parts the Hatchetigbee formation is brought into contact with the lower part of the Marianna limestone ("chimney rock").

The Jackson fault is well shown in the south bank of Stave Creek a quarter of a mile north of the center of sec. 19, T. 7 N., R. 2 E. The fault plane is not exposed but a bluff consisting of 40 to 50 feet of the Tallahatta buhrstone is within 225 feet of an exposure of 25 feet of "chimney rock" on the same level. The upthrow is on the east side and the displacement, which brings what is believed to be the upper part of the Tallahatta into contact with the "chimney rock," amounts to at least 300 feet and possibly as much as 400 feet. Half a mile northwest of this locality the "chimney rock" appears to be in contact with the Lisbon formation, but beyond that no definite evidence of the fault was found. To the southeast evidence of the fault is present at a number of places. One mile north of Jackson on the road to Parkers Chapel there is a broad sink hole on the west side of the road, suggesting the presence of limestone of Vicksburg age, whereas a short distance farther north the lowest beds of the Jackson formation are exposed on the west side of the road near Erasmus Taylor's house. The upper beds of indurated marl of the Claiborne and the lower clay beds of the Jackson formation are poorly exposed near Larkin King's house, in the SW. ¼ sec. 10, T. 6 N., R. 2 E., 3 miles southeast of Jackson, at an altitude of about 65 feet above sea level. One-eighth of a mile east of this locality the Hatchetigbee formation is exposed from the base of a hill up to about 180 feet, and the Tallahatta buhrstone is exposed from that level to the hilltop, about 240 feet above sea level. (See section A-A′, Pl. XXVI.) It is evident that the Jackson fault passes between these two localities and that it has a throw of at least 250 to 300 feet.

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[1] Cooke, C. W., informal communication.

In the SE. ¼ SE. ¼ sec. 16, T. 6 N., R. 2 E., 100 yards northeast of W. F. Calloway's house, 15 feet of soft white "chimney rock" is exposed, and the hills to the east are formed of clays of the Hatchetigbee formation, capped by the Tallahatta buhrstone. The fault here has a throw of at least 400 feet and possibly more. Similar relations are found in the SE. ¼ sec. 9, T. 5 N., R 2 E., where the contact of the "chimney rock" and "horsebone" is exposed at an altitude of about 95 feet above sea level, whereas one-eighth of a mile to the east the clays of the Hatchetigbee are seen on the side of a steep round hill up to an altitude of 265 feet. The throw of the fault here is 450 to 500 feet. A belt of poorly exposed Marianna limestone appears to extend along the west side of the fault continuously from the Central Salt Works to Paynes and is in contact with the Hatchetigbee formation on the east side.

The throw of the fault appears to be greater near its south end. The dip on the upthrown (east) side of the fault is at an angle of a fraction of a degree to 1° or 2° away from the fault; the dip on the west side is determinable at only a few places, where it is toward the fault.

MINOR FOLDS AND FAULTS.

A small fault having a northwest trend is well exposed in the roadside 1 mile north of Winn, near the center of the NW. ¼ sec. 18, T. 8 N., R. 2 E. Here the sand member of the Jackson is thrown against the top part of the Red Bluff clay. The upthrow, which amounts to about 60 feet, is on the west side of the fault. One mile northwest of this locality, in the south bluff of Doatys Creek, the basal clay member of the Jackson is thrown against the lower part of the Red Bluff clay. One mile east of Winn the presence of the fault is also inferred from the relation of the Jackson and Marianna formations. No attempt was made to trace this fault farther to the north or south.

At Paynes a bluish-green sand is exposed in the banks of Fishers Creek near its mouth, whereas in the south bluff of the creek and in the creek about one-third mile above its mouth the upper limestone of the Vicksburg group is exposed. The age of the sand is not known, but it is not in its normal position; it is believed to be of Red Bluff age and to be faulted into its present position. If this inference is true, the fault trends north or slightly northeast and has its upthrow on the west side.

The presence of the Jackson formation in the center of sec. 2, T. 10 N., R. 3 W., near the center of sec. 6 of the same township, and in secs. 2 and 3, T. 10 N., R. 4 W., and the presence of the Tallahatta buhrstone in the bottom of Mill and Okatuppa creeks immediately south of a line connecting these three areas of the Jackson indicate a strongly flexed syncline or a fault with a downthrow on the north side. This area was not studied in sufficient detail to determine the exact structural relations.

POSSIBILITIES OF OIL AND GAS.

GENERAL CONSIDERATIONS.

The study of productive oil fields has yielded much information concerning the occurrence of oil, particularly concerning the age and nature of the containing and associated rocks and of the structural conditions under which it occurs. Little definite information has been obtained, however, as to the processes which give rise to the formation of petroleum and the factors which influence its migration and collection in commercial pools: The application of the knowledge which has been gained to new and unexplored areas sheds some light on the possible occurrence of oil.

There are two problems to be considered. Does oil exist in the region; and if so, where has it accumulated in commercial pools? In some areas, particularly near productive pools, the presence of oil is highly probable provided well-developed anticlines occur and the productive sands of the neighboring fields are present within reach of the drill. Thus, in parts of Oklahoma and on the Sabine uplift in northwestern Louisiana the existence of an anticline is strong evidence of the presence of oil in the underlying rocks. This area in Alabama, however, is so far removed from productive oil fields that the presence or absence of oil in it is the prime consideration and the location of the most promising areas for the accumulation of oil is secondary. Unfortunately geologic evidence here, as in many other places, sheds more light on the probable location of oil, if any is present, than on its presence or absence. Although the drill must prove whether or not oil occurs in the area of the Hatchetigbee anticline, the evidence of its presence and especially of its probable location is worthy of consideration.

EVIDENCE OF OIL.

In this area the best evidence of the presence of oil which may have collected in commercial quantities under favorable structural conditions would be a little oil. The absence of seeps of oil or of traces of it in shallow wells, however, is not convincing evidence that it does not exist in the buried rocks, as no trace of oil was found in a number of important fields of this country prior to the tapping of the productive sand by the drill. This was true of the Caddo, De Soto-Red River, and Corsicana fields and seems to be particularly true of all the Coastal Plain fields except those of the salt-dome type. However, the existence of a fault of large displacement in the area under consideration makes the absence of oil seeps more significant than they would otherwise be.

An asphaltic material which has been described as fossil resin has been found near Cocoa post office, in Choctaw County, and near Dayton, in Marengo County, Ala.[1] Samples from both of these localities have been examined by Chase Palmer, of the United States Geological Survey, who reports as follows:

> They begin to soften at 130° C.
> They are partly soluble in ether, giving a fluorescent solution.
> Most of the material insoluble in ether dissolves in carbon tetrachloride.
> The resin test in the alcoholic extract is negative.
> These specimens appear to be asphaltic rather than resinous.

According to Cooke[2] the asphaltic material occurs near Cocoa post office as thin seams 1 inch or less in width in the "*Zeuglodon* bed" of the Jackson formation. The seams, where observed, are parallel to the bedding of the including marl.

Oil is found in sedimentary rocks ranging in age from Cambrian to Quaternary; thus it seems that the age of the rock has little or nothing to do with the occurrence of petroleum, although petroleum is present over wide areas in certain geologic formations. More important than the age of the rocks is the presence of organic matter left by abundant plant or animal life in them—matter which, under conditions little understood, is capable of being transformed into oil and gas. Oil in the Appalachian fields is believed by some geologists to have been derived largely from land plants; whereas part at least of the oil in the fields of the Gulf Coastal Plain is believed to have been derived from marine plants or animals.[3] The Midway, Selma, and Eutaw formations are of marine origin, and contain at their outcrops traces of abundant organic remains, a part of which may have been converted into petroleum since the beds were laid down. The sand and sandy clay immediately overlying the chalk (see log of Cullom Springs well, Pl. XXIX) and the sands at the base of the chalk are considered to be the most favorable beds for the concentration of oil and gas, if they exist in this area.

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[1] Smith, E. A., Johnson, L. C., and Langdon, D. W., jr., On the geology of the Coastal Plain of Alabama, pp. 196-198, Alabama Geol. Survey, 1894.

[2] Cooke, C. W., informal communication.

[3] Matson, G. C., and Hopkins, O. B., The Corsicana oil and gas field, Tex.: U. S. Geol. Survey Bull. 661, pp. 241-244, 1917 (Bull. 661-F).

The Tuscaloosa formation, which lies below the Eutaw, contains both subaerial and semimarine deposits, and in the area of its outcrop some of its beds carry vegetable remains. The possibilities of the occurrence of oil in this formation are twofold—the oil may have been derived from the transformation of the organic material contained in it, or it may have been derived from the Paleozoic rocks which doubtless underlie it[1] and which in the area to the north are in part carbonaceous and bituminous. The fact that this formation is so thick and so dominantly sandy detracts from its possibilities of yielding oil and gas, as fairly thin but persistent sand beds in the midst of thick deposits of clay or shale seem to present the most favorable condition for their accumulation. Oil is more likely to occur in the overlying formations than in this formation.

The deformation of an area has in several ways an important bearing on the possible occurrence of oil—it may aid the transformation of organic débris into petroleum, it may aid in the transfer of the petroleum from fine-grained to coarser-grained beds and in the migration in those beds, and it may produce folds suitable for the trapping of commercial pools of oil and gas. The wide distribution of petroleum in Louisiana and Texas and its general absence, so far as known, in the States east of Mississippi River where beds of the same age and general character have been deposited may be due in part to the greater deformation of the same strata in those States. However, so far as known, the deformation has been greater and more pronounced folds and faults have been developed in the area here discussed than in any other area of the Coastal Plain east of the Mississippi. Therefore, so far as the deformation is concerned this area is particularly favorable for the occurrence of oil and gas.

The Hatchetigbee uplift is so far removed from productive fields where the geologic conditions are similar that a comparison between them is of little value. The nearest comparable fields are those of northwestern Louisiana, the Caddo and De Soto–Red River fields. In both regions the beds of Wilcox age crop out at the surface and are underlain by beds of the same age; the structure here is more strongly developed than there; the general succession of beds in the upper part of the section, including the Midway, Ripley, and Selma, is somewhat similar in the two areas, but the lower formations are widely different.

The following data regarding deep drillings in this area are given because of their bearing on the possible occurrence of oil and gas.

---

[1] The Tuscaloosa may be separated in this area from the Paleozoic rocks by deposits of Lower Cretaceous age, such as are found to the east and west.

This information was taken largely from a report by Smith[1] supplemented by the meager information obtained during the field studies.

Cullom Springs well, three-fourths mile west of Bladon Springs, Choctaw County; drilled in 1884–85 by Capt. Trowbridge; depth, 1,345 feet; starts in Hatchetigbee formation and reaches the upper part of the Selma chalk (see log, Pl. XXIX); yields strong flow of salt water and some gas. (See analysis, p. 311.)

St. Stephens Oil Co.'s well, in sec. 27, T. 7 N., R. 1 W., in the northwest corner of the old Spanish grant known as the John McGrew tract, about 1,600 feet from Oil Well Landing on Tombigbee River, above St. Stephens Landing, Washington County, drilled in 1902 by James Keoughan, contractor; depth, 2,006 feet; starts in upper part of Claiborne group (probably Lisbon formation) and may reach the Selma chalk.

Well at Beckhams Landing, near Salitpa, Clarke County; drilled 1903–4; depth 2,600 feet.

Well at lock No. 1, Tombigbee River, Clarke County; drilled by Maj. Hill; depth reported to be about 2,700 feet; yields flow of salt water and some gas.

Bolen well, in the northeast corner of the SE. ¼ SE. ¼ sec. 17, T. 7 N., R. 1 E., northwest of Jackson, Clarke County; drilled in 1902–3 under direction of S. A. Hobson; depth, 740 feet; yields salt water and some gas. (See analysis, p. 311.)

Edgar Oil Co.'s well, in the NW. ¼ SW. ¼ sec. 26, T. 7 N., R. 1 E., northwest of Jackson, Clarke County; drilled in 1903–4 by W. R. Osborne; depth, 1,201 feet; started in Marianna limestone.

Bush well, on State land near center of sec. 27, T. 7 N., R. 1 E., northwest of Jackson, Clarke County; drilled in 1902 by George D. and W. R. Osborne for T. G. Bush & Co.; depth not known, but reported to be more than 800 feet; near outcrop of base of Jackson formation.

Salt Mountain well, in the southwest corner of the NW. ¼ SW. ¼ sec. 34, T. 6 N., R. 2 E., 6 miles south of Jackson, Clarke County; drilled in 1904-5 under the direction of S. A. Hobson; depth 921 feet; near outcrop of Marianna limestone.

Of these eight wells the one most favorably located structurally is that at Cullom Springs, which probably reaches the upper part of the Selma chalk. All the other wells are unfavorably located structurally and yield little or no information regarding the possible occurrence of oil and gas in the upper part of the Hatchetigbee anticline. The Cullom Springs well is disappointing in that it did not make a better showing. However, the lack of information regarding the depths at which casings were set makes it impossible to draw any positive deductions as to the content of the sands penetrated. (See analysis of gas from this well, p. 311.)

With the exception of the Cullom Springs well (see Pl. XXVI), all the wells drilled in this area in search for oil were located near salt-water seeps and shallow salt-water wells, because it was believed that salt water indicated the presence of a salt dome, with which oil is commonly associated in the Gulf coastal region. The results of the drilling of these wells and the study of the area show conclusively that no salt domes are present here, although it is unusual to find salt water within a few feet of the surface in the Gulf coastal region where salt domes are not present. The salt water which is associated with a small quantity of inflammable gas, is found in four areas, generally more or less closely associated with the outcrop of the Hatchetigbee, formation, as follows: At the Lower Salt Works, in secs. 21 and 28, T. 5 N., R. 2 E., 12 miles south of Jackson; at the Central Salt Works, in secs. 33 and 34, T. 6 N., R. 2 E., 6 miles south of Jackson; at the Upper Salt Works, in secs. 16, 17, and 21, T. 7 N., R. 1 E., 6 miles northwest of Jackson; and in Washington County, 4 to 6 miles north of St. Stephens, mainly on Tauler Creek. The general association of the salt water with the Hatchetigbee suggests that it may be derived from that formation, which would be normally about 400 to 500 feet below the surface in this area if it were not for the folding and uplifting of the rocks. However, the salt water may be derived from deeply buried formations and reach the surface along the fault, which is described on page 305.

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[1] Smith, E. A., Underground water resources of Alabama, Alabama Geol. Survey, 1907.

It was thought that if the salt water has escaped from underlying formations along faults the associated gas might shed some light on the possible occurrence of oil in the deeply buried rocks. Consequently samples were collected from a shallow salt-water well and from two wells drilled in search for oil, and they have been analyzed with the following results:

Analyses of gas from wells near Bladon Springs and Jackson, Ala.

[F. M. Seibert, Bureau of Mines, analyst.]

	8485	8488	8487
CO_2	1.1	1.3	1.2
O_2	.5	.2	.0
CH_4	70.1	91.8	91.0
N_2	28.3	6.7	7.8
	100.0	100.0	100.0
Specific gravity (air=1)	0.68	0.60	0.59
Heating value per cubic foot at 0° C. and 760 millimeters pressure...B. t. u.	773	990	969

8485. Cullom Springs well, near Bladon Springs, Ala.
8488. Bolen well, SE. ¼ SE. ¼ sec. 17, T. 7 N., R. 1 E., 9 miles northwest of Jackson, Ala.
8487. Shallow salt well 100 yards north of Bolen well.

To judge from these analyses, the gases may be of either surface or deep-seated origin, as they fall within the range in composition of both types and have none of the diagnostic characters of either. It is significant that they do not leave an oily film on the water and they do not contain any ethane, which is characteristic of many but not all deep-seated gases. These analyses shed no light on the presence or absence of oil and deep-rock gas in the underlying formations.

The presence of salt water in the underlying formations is a somewhat favorable indication, for oil and gas are commonly associated with salt water. It suggests that there has not been a vigorous circulation of the fluids in the underlying rocks, which might have led to the loss of any petroleum contained in them, as the free movement of the water aids the movement of the petroleum. If the circulation had been vigorous fresh water and not brines would have been found in the underlying beds.

MOST FAVORABLE AREAS FOR PROSPECTING.

Where water, oil, and gas fill a folded porous bed, they tend to separate according to their relative gravity; the gas, which is lightest, fills the crests of the upfolds, the oil comes next, and the water is below that. The areas occupied by each of these materials depend on their relative amounts. If much gas is present in proportion to the size of the fold, the oil will be found down on its flank; if little or no gas is present the oil may occupy the crest of the fold. In general, the crest of a fold and particularly high areas along the crest are most promising and should be tested first. Oil is found also on the flanks of a fold where there are minor folds or where the rate of dip changes or in areas of porous sands.

The Hatchetigbee anticline has a more favorable structure for the accumulation of oil and gas than the Jackson fault, although the most favorable areas along both are worthy of tests. The Hatchetigbee anticline is capable of effecting the accumulation of oil and gas migrating up or down the dip, either from the northeast or from the southwest, and there seems to be little or no opportunity for its escape to the surface, as the fold is believed not to be extensively faulted. The Jackson fault, on the other hand, seems to present favorable conditions for oil accumulation only on its east side, and oil could have accumulated there only by migrating up the dip from the east. There is also the possibility that any oil accumulating thus may have escaped along the fault plane, although no evidence of such an escape exists.

The most favorable areas on the Hatchetigbee anticline for testing are along the crest of the anticline from Jackson Creek to Turkey Creek and particularly near Salitpa, from sec. 5, T. 7 N., R. 1 E., to sec. 22, T. 8 N., R. 1 W., and near Bladon Springs from sec. 19 to sec. 34, T. 9 N., R. 2 W. Other favorable areas for testing are along Mill Creek in secs. 4, 9, 16, and 21, T. 10 N., R. 3 W.

The most favorable area along the Jackson fault for testing is a belt about 1 mile wide along its east side, stretching from sec. 21, T. 5 N., R. 2 E., to sec. 10, T. 6 N., R. 2 E. The underground conditions along this belt are essentially the same as those along the crest of the Hatchetigbee anticline; the Hatchetigbee formation is at the surface, and the underlying sands will be encountered at about the same depth as along the crest of the anticline. The beds are somewhat higher in the southern half of this belt, and the conditions there are somewhat more favorable for the accumulation of oil and gas.

If the areas described above as the most promising in the region covered by this report are found to be productive of oil or gas, there are other areas in the neighboring region which are worthy of investigation. This is particularly true of the area along Chickasawhay

PLO

River between Waynesboro and Hiwannee, referred to on page 305, and the area along the Lower Peach Tree anticline, as described by Smith and others.[1]

DEPTHS TO PROBABLE PRODUCTIVE FORMATIONS.

The nearest sands above and below the Selma chalk are considered the most favorable for oil and gas. The position and thickness of the sands above the chalk are shown in the plotted log of the Cullom Springs well in Plate XXIX. This log shows the presence of three sands within about 400 feet above the Selma. The sands that occur at 780, 900, and 1,200 feet in this well will be found, if present, at about the same depths along the crest of the Hatchetigbee anticline from Bladon Springs to Salitpa. Although these sands were penetrated in the Cullom Springs well and found to be unproductive, they may be productive on other parts of the anticline.

The base of the Selma, which is about 1,000 feet thick at its nearest measured locality, will be reached here at about 2,200 feet. The Eutaw formation, which lies below the Selma, contains at its outcrop much sand and sandy clay, as shown in Plate XXIX. The thickness of this formation in this area is not known; at its outcrop to the north it is 400 to 500 feet thick,[2] and it is probably not thicker than that here. If this is the correct thickness the base of the Eutaw will be reached here at about 2,700 feet. This formation should be carefully tested for oil and gas, as it has not been penetrated in this area. The maximum thickness of the Tuscaloosa is given at 1,000 feet,[2] but it is doubtful whether the formation attains that thickness in this area. The maximum depth at which the base of the Tuscaloosa should be reached is thus about 3,700 feet. It is quite likely that the Lower Cretaceous beds will be found below the Tuscaloosa, as they crop out in east-central Alabama and appear to be overlapped to the west. Their thickness and character here are matters of speculation.

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[1] Smith, E. A., Johnson, L. C., and Langdon, D. W., jr., On the geology of the Coastal Plain of Alabama: pp. 207-211, Alabama Geol. Survey, 1894.

[2] Stephenson, L. W., Cretaceous deposits of the eastern Gulf region: U. S. Geol. Survey Prof. Paper 81, p. 20, 1914.

PHOSPHATIC OIL SHALES NEAR DELL AND DILLON, BEAVERHEAD COUNTY, MONTANA.

By C. F. Bowen.

INTRODUCTION.

Reported occurrences of oil shale in Montana led to a preliminary investigation by the United States Geological Survey in the early part of October, 1916, of two localities, one in what is known as Muddy Creek basin, 8 or 10 miles west of Dell, and the other in Smallhorn Canyon, about 10 miles south of Dillon. (See fig. 33.) The oil shale that promises to be most valuable occurs at about the same horizon as the phosphate deposits of Montana, Idaho, and Wyoming and, in addition to the oil it yields, contains considerable phosphate. Laboratory tests have shown that the phosphate is not driven off by distillation, and the fact that the shale yields oil on distillation and yet retains a notable quantity of phosphate in the ash presents to the technologist a problem whose solution may be economically as valuable as it is scientifically interesting.

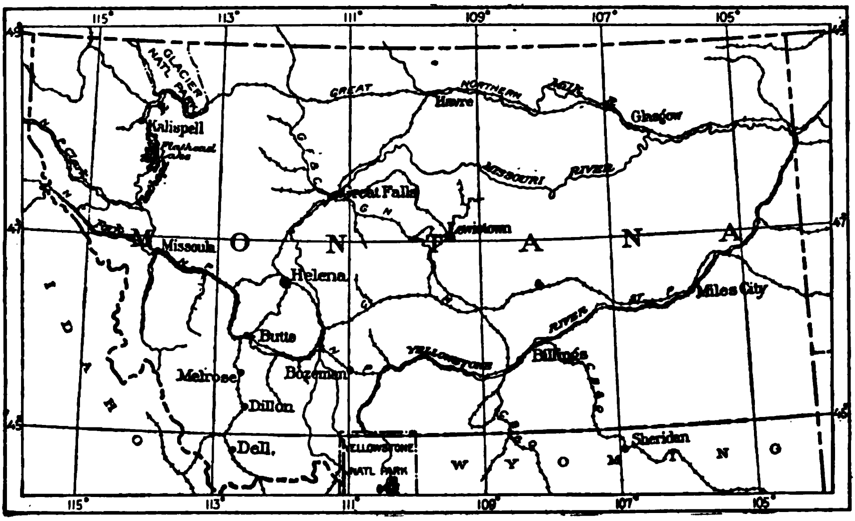

FIGURE 33.—Index map showing location of Dell and Dillon, Beaverhead County, Mont.

STRATIGRAPHY AND STRUCTURE.

The strata are greatly disturbed by folding and faulting; at some places they are very much shattered and stand nearly vertical, so that the sequence of formations is difficult to determine by hasty examination, but the sequence in the Muddy Creek basin seems to be as follows:

1. A hard vitreous quartzite, probably a few hundred feet thick, seems to be the oldest sedimentary rock. This quartzite was not seen in normal position at any place, but on Muddy Creek and at the mouth of Smallhorn Canyon it appears to underlie limestone of probable Mississippian age. No fossils were obtained from the quartzite, and its age is therefore not known.

2. Apparently upon the quartzite lies a gray, massive to thick-bedded crystalline limestone, which at Smallhorn Canyon and at Sheep Canyon, about 2 miles southeast of Smallhorn Canyon, seems to be conglomerate at the top. The conglomerate is overlain by a bed of red shale, and both the conglomerate and the shale may belong to an overlying formation. A few fossils obtained from this limestone are believed by G. H. Girty to be of Mississippian age.

3. Overlying the limestone (No. 2) is a great thickness of sandstone containing some highly calcareous beds and possibly some true limestone and chert. This formation was not studied in detail, and no fossils were obtained from it. It seems to correspond in position to the Quadrant quartzite.

4. The thick sandstone (No. 3) is overlain by a few hundred feet of gray limestone, which is covered by sandy beds. Fossils obtained both from the limestone and from the sandy beds are assigned by Mr. Girty to "the Phosphoria formation, now regarded as of Permian age."

5. The gray limestone (No. 4) is overlain by 1,500 feet or more of thin-bedded pinkish limestone, in which there may be some beds of shale. Fossils obtained from the lower part of this limestone are provisionally referred by Mr. Girty to the Lower Triassic.

6. Upon this thin-bedded limestone (No. 5) perhaps unconformably lies a series of red beds, which are highly conglomeratic at the base.

7. The greater part of Muddy Creek basin is occupied by a series of fresh-water conglomerates, sandstones, shales, and limestones, from which were obtained a few fossil shells and leaves that indicate Tertiary age. These fossils are not sufficiently distinctive, however, to fix the age more definitely. The beds appear to overlap the underlying formations and vary considerably from place to place in lithologic character and in color, the prevailing colors being

green, gray, brown, and white. Some of the sandstones appear to be tuffaceous. Conglomerate is distributed more or less through the mass but is most abundant in the lower part.

THE OIL SHALE.

OCCURRENCE AND PROPERTIES.

The interesting thing in connection with the section described above is the occurrence in it of oil shale at two horizons, one at the top of No. 4 (Phosphoria (?) formation) and the other in the Tertiary lake beds. Both these shale zones are exposed in Muddy Creek basin but only the lower one is exposed in Smallhorn Canyon, the Tertiary beds not being represented there.

The lower shale is exposed on the east side of Muddy Creek basin and dips westward at an angle of 25° to 30°. The shale is black, gives a brownish streak, and has an oolitic texture. In general the oolites seem to be distributed promiscuously, but in some specimens there are narrow bands nearly devoid of them. On fracture the shale shows what appears to be slipping planes, which have a glistening, oily, or waxy-looking surface on which a slight iridescence is in places noticeable. When rubbed a freshly broken surface emits an unmistakable odor of petroleum, and when placed in a fire the shale will burn. A dry distillation test on a small sample yielded 9 gallons of oil per ton, but a test made on a larger sample gave only 7.5 gallons per ton. As this shale resembles shales that are associated with the phosphate beds of Idaho and Wyoming it was tested roughly for phosphate. The test showed that it contains considerable phosphate and led to a more detailed analysis of a larger sample.

The upper shale horizon occurs about the middle of the Tertiary lake beds (No. 7 above) and is exposed about one-fourth mile west of MacKay's oil rig. This shale, when fresh, is light brown, but it weathers nearly white, though in places it bears a yellowish coating. In the process of weathering the shale breaks up into thin laminae or flakes resembling manila paper. It contains an abundance of vegetal remains and some well-preserved leaves, chiefly of *Sequoia.* This shale, like that from the lower horizon, will burn when exposed to a strong flame, but does not give an odor of petroleum on freshly broken surfaces. On distillation it yields about eight gallons of oil per ton. The bed is about 100 feet thick. Thinner beds occur in other parts of the section, some of which contain thin streaks of lignite. In fact, except for its somewhat lighter color, the shale has very much the aspect of an ordinary carbonaceous shale, such as is commonly associated with coal beds.

About 10 miles south of Dillon, 2 miles above the mouth of Smallhorn Canyon, a bed of oil shale that is believed to lie at about the same horizon as the lower shale in Muddy Creek basin is exposed. The bed has been opened up by a tunnel about 150 feet long, driven in the hope of finding coal. The shale is dark brown, tough, and dense, without oolitic texture. It contains numerous megaspores and minute bodies of vegetable origin. A sample representing a thickness of about 5 feet taken from the tunnel mentioned above yielded, on distillation, 24 gallons of oil per ton. In its natural state, however, it does not give any odor of petroleum. It also contains only a small quantity of phosphate.

ANALYSES OF THE SHALE.

Analyses of a sample of the shale from Muddy Creek basin and from the lower horizon in Smallhorn Canyon are as follows:

Analyses of oil shale from Muddy Creek basin and Smallhorn Canyon, Mont.

[Chase Palmer and R. M. Kamm, analysts.]

	Petroleum.			Phosphoric acid.		Equivalent in calcium phosphate $(Ca_3(PO_4)_2)$.	Potash.
	Dry distillation.	Ether extraction.	Carbon tetrachloride extraction.	Original sample.	After incineration.		
	Gallons per ton.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Muddy Creek basin	7.5	0.2	0.45	15.56	15.57	33.96	0.39
Smallhorn Canyon	24.0	....	....	2.62	2.53	5.70	.46

Perhaps the most interesting and significant fact in connection with the analyses is the association of phosphate and oil in considerable quantities in shales which seem to occur at or near the same horizon as the extensive phosphate beds of Idaho, Wyoming, Utah, and parts of Montana. Evidences of petroleum or bituminous compounds have been observed over wide areas by those who have worked on the phosphate deposits, but few if any tests have heretofore been made to ascertain the quantity of oil in the rocks. The quantity of phosphate is much greater in the oolitic than in the nonoolitic shale, which suggests that there may be some relation between oolitic texture and phosphate content. Another feature is the fact that the content of phosphoric acid is not affected by burning the shale, for the quantity of phosphate in the ash is almost exactly the same as that in the original sample. The phosphate seems to be present as a mineral and not as an organic compound, its form being probably a result of the metamorphism of the rocks. The fact that the phosphate occurs as a mineral and is not decomposed by the heat required to distill the shale may have an important technologic application, as the oil in the shale might be used as fuel to calcine the phosphate if calcination is desirable. A more promising investigation, however, would be directed to the utilization of the ammonia in the oil to produce ammonium phosphate, a small quantity of oil being obtained as a by-product. Unless some such combination can be worked out the samples tested are not rich enough in either phosphate or oil to be of present value. However, as the shale was sampled at only one place in each locality and as its phosphatic character was not surmised at that time but was discovered later in the office, it is possible that richer material may be discovered, especially material richer in phosphate, as high-grade phosphate occurs at Melrose, about 30 miles north of Dillon.

Considered as to their oil content these are true oil shales for they contain no free oil. The oil is obtained from them by the destructive distillation of their vegetable matter, almost no oil having been obtained by extraction tests. Furthermore, as noted by Chase Palmer, the ethereal extract seems to be of mineral rather than vegetable composition—that is, it probably exists as some form of mineral wax or other hydrocarbon produced by the distillation of a part of the original organic matter in the shale. This distillation could have been effected by the metamorphism to which the rocks have been subjected, shown by the folding, faulting, and squeezing manifest at many places and by the crystallization of the limestone. A considerable part of the organic matter that was originally in the shale may therefore have undergone partial distillation, a supposition that in turn may account for the relatively small quantity of oil obtained from these shales. If the shales have already undergone partial distillation, what has become of the distillate? Obviously one of two things has happened. Either the oil has escaped into the atmosphere or it is still retained in the rocks. Where the shales are exposed, as in Muddy Creek basin, the oil has undoubtedly escaped, and this may account for the slight yield on extraction from shale that gives off a strong odor of petroleum. Where the shales are not exposed they may have been a source of supply of petroleum in areas where the structural conditions are favorable to its accumulation. It may therefore be possible that commercial accumulations of oil have been formed in these older (Paleozoic) rocks. If this should prove to be true, it would open up a new field for exploration in the West. Thus far the Lander oil field, in Wyoming, seems to be the only place where oil has been obtained in commercial quantities from the Paleozoic rocks in the Rocky Mountain region, though indications of oil have been noted at several other places in Wyoming and in southern Utah.

DISTRIBUTION.

In the preliminary examination here described no attempt was made to trace these shales and determine their distribution. The writer received numerous reports of the occurrence of similar shale in other places, particularly around Lima and in Horse Prairie. As the shale at the lower horizon is interbedded in Paleozoic rocks and is closely related to if not identical with the shale at the phosphate horizon it is probably widely distributed. Whether or not it is equally petroliferous throughout the known phosphate area remains to be determined, for the phosphate shales at other localities have not yet been tested for oil.

The shale in the Tertiary lake beds is probably much less widely distributed than that in the Paleozoic rocks, for the lake beds, which show considerable variation in lithology, were probably deposited in small areas.

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no. 660-661

Verify 3 sheet (s)
in pocket

MAY 0 3 2004